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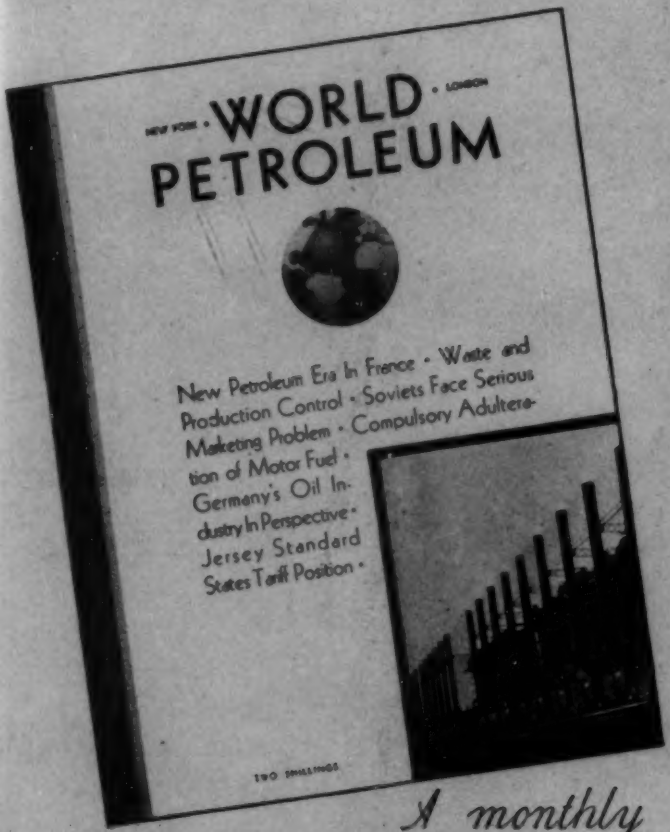
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Abstracts. Abstracts of the more important articles and patent specifications are published with each issue of the Journal, this supplement being paged independently of the transactions. Members desiring to have the Abstracts printed on one side of the paper only can be supplied with these at a charge of 10s. per annum per copy, payable in advance.

Medals. The Redwood Medal is awarded, at the discretion of the Council, to the person who shall have made the most meritorious contribution to petroleum technology, in the form of a paper or papers published in the Journal of the Institution, during two successive sessions, preference being given to original work and to papers which have been read before the Institution and discussed. The award is not confined to members of the Institution and may be withheld if no contribution is considered to be of sufficient merit.

A medal and a prize of five guineas is awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented the best paper during the session.

Benevolent Fund. The Benevolent Fund is intended to aid necessitous persons who are or have been members of the Institution, and their dependent relatives.

The Fund is raised by voluntary annual subscriptions, donations, and bequests, and all contributions should be sent to the Secretary of the Institution at Aldine House, Bedford Street, London, W.C. 2. The Fund is administered by the Council through the Benevolent Fund Committee, and all applications in connection therewith must be made on a special form which can be obtained from the Secretary of the Institution.

Appointments Register. A register of members requiring appointments is kept at the office of the Institution for the convenience of firms requiring the services of petroleum technologists, etc., it being understood that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library may be consulted between the hours of 11 a.m. and 4 p.m. daily. (Saturdays, 11 a.m. to 12 noon.)

Advertisements. Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from Mr. Thomas Tofts, 301-302, Bank Chambers, 329, High Holborn, W.C. 1. (Telephone No. Hol. 4776.)

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Mr. A. G. V. BERRY is coming home from Trinidad.

Mr. G. S. DILLEY is returning from Sarawak.

Mr. W. ENGLISH has returned to Egypt.

Mr. R. W. FARMBOROUGH has left Germany and is in England.

Mr. C. J. FIELDER is home from Persia.

Mr. N. W. GREY is coming home from Peru.

Dr. J. A. L. HENDERSON has left for Canada and the U.S.A.

Mr. G. H. HUBBARD is home from Persia.

Dr. W. KAUENHOWEN has left U.S.A. and is now in Germany.

Mr. C. LIESHOUT is in Holland.

Mr. I. MCCALLUM is home from Persia.

Mr. E. J. MILLAR has returned from Burma.

Mr. W. G. C. TOMALIN has left Rumania and is now in Holland.

Mr. V. J. WILMOTH is coming home from Burma.

Dr. C. H. Lander, C.B.E., has been appointed to the chair of Engineering at the City and Guilds College, Imperial College of Science and Technology. In 1922 he was appointed Deputy Director of Fuel Research, and on the retirement of Sir George Beilby in 1923, became Director, a post which he has held until the present time.

The Secretary would be glad to hear of the whereabouts of the following members: C. A. Bauduin, J. D. Bing, N. M. Brodie, E. H. Crush, L. B. Holloway, C. E. Jobling, H. Leslie Little, Nand Lal Pasi, E. C. Scott, W. E. Shepherd, C. M. Stoney, John C. Templeton, R. K. Van Sickle, F. E. G. Watson and S. S. Webb-Bowen.

DINNER CLUB.

The attention of members is drawn to the Dinner Club of the Institution. This Club holds informal dinners after each General Meeting of the Institution and members may invite guests. Those desiring to receive notice of these dinners are requested to inform the Secretary of the Institution.

THIRTEENTH ANNUAL DINNER.

The Thirteenth Annual Dinner of the Institution of Petroleum Technologists will be held at the Connaught Rooms, London, on October 9th, 1931.

SMALL ADVERTISEMENTS.

In future the advertisement columns of the Journal will be open for the inclusion of small prepaid advertisements, such as Situations Vacant and Wanted, Patents for Sale and Miscellaneous, at a charge of 1s. 0d. per line of seven words (minimum 4s. 0d.). A charge of 1s. 0d. will be made for the use of a box number. Matter for insertion should be in the hands of the Associate Editor not later than the 12th of the month in which it is desired that the advertisement should appear.

B.T.L. MONTHLY BULLETIN.

Under the above title, Messrs. Baird & Tatlock (London), Ltd., are issuing a new monthly publication, each issue of which will describe some new apparatus and will contain a foreword written by an expert on the subject for which the apparatus is used. The first issue (May) deals with some applications of the Thermionic Valve.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND THIRTY-FOURTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, March 10, 1931, Dr. A. E. Dunstan, President, occupying the chair.

The Secretary read the alterations proposed to be made in the By-laws at the Annual General Meeting on March 31.

The President said it would be within the recollection of members that about a year previously the Institution had heard an important paper by Major Goddard on the high speed Diesel engine, more particularly for use in road transport. At the present meeting the story was to be carried a degree further, with a paper on fuel testing in slow and high speed Diesel engines, by Messrs. Le Mesurier and Stansfield. It was unnecessary for him to add that Mr. Le Mesurier was one of the foremost authorities on that subject, and anything he said would be regarded as highly authoritative. Mr. Stansfield they were glad to have the opportunity of welcoming back from his visit to Detroit, where he, with Messrs. Sprake and Barton, had represented the Institution at the January Meeting of the Society of Automotive Engineers.

The following paper was then read :—

Fuel Testing in Slow and High Speed Diesel Engines

By L. J. LE MESURIER, M.I.N.A., M.Inst.Mar.Eng., and R. STANSFIELD, A.M.Inst.C.E. (Members).

THE problems presented by the use of fuels in heavy oil engines are necessarily complicated by the very wide range of fuels which may be used and by the large number of different types of engines involved. Large air injection Diesel engines and, in general, large oil engines operating at moderate speeds, are capable of using the widest range of fuels ; and engines of this type may be found operating successfully on petroleum products extending from the kerosine fractions to heavy residuals. In addition, fuels such as those derived from coal tar or of vegetable origin are used.

Within recent years, however, the heavy oil engine field has been considerably extended and notably in the direction of small power units of the type which are tending to displace paraffin or petrol engines in marine, traction and small stationary plants. There is also a tendency towards a general increase in speed and in the adoption of airless injection, and the whole development calls for a more critical examination of fuel characteristics and fuel behaviour under engine conditions than was previously necessary.

Slow running engines of large power, working at constant speed, undoubtedly show differences in fuel requirements according to

type, but such differences are more under control and the conditions of operation are usually such that adjustments to blast air pressure or fuel valves may be made to suit the particular fuel in use.

The small high speed engine is frequently called upon to work under less favourable conditions than the larger type. Wide variations in speed and load may be necessary—as in the case of a vehicle engine—and the small size of the unit definitely precludes the possibility of the skilled attention that can be given to the larger plant.

The present situation is somewhat similar to that which existed in relation to petrol about twelve years ago when Tizard and Pye and Ricardo commenced an investigation of the behaviour of motor fuels. Prior to that time the phenomenon of pinking was known, but there was little information regarding its connection with fuel classification or its effect on engine output; nor was the relation between compression ratio and efficiency established on a practical basis. Since that date research on the lighter hydrocarbon fuels has been carried on in an intensive manner throughout the world (principally in Great Britain and America); and a point has now been reached where the formulation of an international method of testing fuels for anti-knock value in a standard testing engine is in active progress.

The research about to be described includes an attempt to cover certain aspects in the behaviour of a series of typical fuels in both slow and high speed Diesel engines. As far as possible it has been directed towards problems presented directly by engine users and also towards more fundamental aspects of combustion which, it is believe, need to be more generally understood before the mechanism necessary for combustion, particularly at high speeds, can be perfected.

The programme of work included an examination of fuel consumption, fuel system leakage, the combustion process from the point of injection through the delay period to the beginning of expansion, combustion shock, ease of starting, the effect of dopes, the effect of nozzle alterations and the effect of changes in speed in relation to combustion and shock.

Many of the results obtained are to be regarded as first approximations, since only standard engines have been used for the tests, and designs which may be quite satisfactory for commercial work are not necessarily the best for research purposes. It is felt, however, that the broad indications are sufficiently clear to justify their publication, and that tests on a special engine or engines designed specially for research work are unlikely to affect the general conclusions reached.

Fourteen different fuels have been examined and full particulars of their chemical and physical characteristics are given in *Table I*.

TABLE 1

Fuel No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Sp. Gr. at 60° F. ..	0·867	0·870	0·877	0·896	0·833	0·852	0·867	0·855	0·896	0·904	0·910	0·929	0·978	0·793
Flash Point (P.M.) °F. ..	236	226	220	190	182	188	184	208	184	206	202	176	128	102
Set Point °F. ..	8	12	22	37	12	0	—20	—10	—20	—20	—20	—2	—20	—89
Kinematic Viscosity at 32°F. ..	·1946	—	·7856	—	·0735	·0840	·1379	·1297	·1335	·1528	1·183	—	Solid. sep.	—
70°F. ..	·0846	·1240	·1778	·5439	0·425	0·453	·0640	·0599	·0624	·0653	·2964	·2019	·0970	·0204
100°F. ..	·0520	·0735	·0987	·2318	·0295	·0307	·0403	·0396	·0412	·0412	·1407	·1014	·0520	—
140°F. ..	·0317	·0428	·0542	·1021	·0212	·0209	·0250	·0254	0·266	·0254	·0882	·0520	·0276	·0114
Cal. Value.														
Gross B. ThU's./ Net .. lb.	19,500	19,450	19,390	19,280	19,700	19,800	19,700	19,675	19,200	19·150	19,220	19,250	16,800	20,040
	18,290	18,250	18,200	18,100	18,460	18,600	18,490	18,460	18,170	18,050	18,080	18,170	15,940	18,720
Sediment % ..	·002	·004	·006	·008	·007	·009	·007	·008	·002	trace.	·011	·016	·126	nil
Ash %	·001	·001	·003	·005	·002	·004	·002	·003	trace.	trace.	·003	·006	·021	nil
C.	85·60	85·58	85·56	85·51	85·61	85·69	86·50	85·41	86·86	86·60	85·63	87·62	82·05	—
H.	12·69	12·60	12·53	12·36	13·08	12·65	12·77	12·82	11·86	11·63	12·02	11·40	9·05	—
C/H Ratio ..	6·7	6·8	6·8	6·6	6·6	6·8	6·8	6·7	7·3	7·5	7·1	7·7	9·1	—
S.	1·07	1·17	1·27	1·41	0·54	0·85	0·11	0·63	1·01	0·50	1·62	0·16	0·63	0·06
Hard Asphalt % ..	nil	0·26	0·47	1·02	nil	nil	nil	0·10	0·09	trace.	0·11	0·06	2·62	nil
Soft Asphalt % ..	nil	0·80	1·60	3·50	nil	nil	nil	nil	0·43	nil	nil	nil	0·02	nil
Carbon Residue%	0·06	0·81	1·65	3·73	0·01	0·01	0·02	0·17	1·09	0·13	0·17	0·50	2·02	nil
S.I. Temp., °C. ..	262	262	262	265	266	268	261	262	279	272	266	273	520	250
I.B.P. °C. ..	256	219	213	208	205	205	214	226	207	236	209	194	127	162
Vol to 200°C.% ..	—	—	—	—	—	—	—	—	—	—	—	0·5	23	30
225°C.% ..	—	1·5	2·5	3·5	3	3	3·5	—	10·5	—	1·5	5	56	68·5
250°C.% ..	—	4·0	6	11	20·5	22·0	17·5	20	48	18	3·5	16	69	88
275°C.% ..	10·5	15·0	17	19	53	61	44	48·5	72·5	51	10·5	32·5	78	96
300°C.% ..	42·5	43·0	37	27·5	77	80	68·5	70·5	80	75·5	20·5	50·5	84	F.B.P. 285°C.
325°C.% ..	71	61·5	56·5	37·5	90	91	83	83	86	87	35	62	90	T.D. 98%
350°C.% ..	89	79·0	72	42	96·5	96·5	93	91·5	89·5	95	55	72·5	96·5	Loss 1%
Residue% ..	11	21·0	28	58	3·5	3·5	7	8·5	10·5	5	45	27·5	3·5	1

An approximate classification of the fuels based chiefly on the type of motor spirit obtained from the crude in each case is as follows :

No. 1. Distillate from mixed base crude—mainly paraffin.
No. 2. Blend of distillate and residue—mainly paraffin.
No. 3. Blend of distillate and residue—mainly paraffin.
No. 4. Residue from mixed base crude—mainly paraffin.
No. 5. Gas oil from Scotch shale (paraffins).
No. 6. Distillate from mixed base crude—mainly paraffin.
No. 7. Distillate from naphthenic base crude.
No. 8. Distillate from naphthenic base crude.
No. 9. Blend of distillate and residue from naphthenic-aromatic base crude—mainly naphthenic.
No. 10. Distillate from naphthenic-aromatic base crude—mainly naphthenic.
No. 11. Blend of distillate and residue from aromatic base crude.
No. 12. Residue from naphthenic base crude.
No. 13. Creosote from low temperature carbonisation of coal.
No. 14. Kerosine from same crude as No. 1.

Particulars of the four engines used for the tests are given below.

Maker.	Type.	Rated B.H.P.	Max. speed.	Bore.	Stroke.
Petter ..	Two stroke Hot bulb	8	625	6 in.	5½ in.
Junkers ..	Two stroke Opp. piston	8	1000	65 m.m.	210 m.m. combined (120 m.m. + 90 m.m.)
McLaren Benz	Four stroke	12	1000	125 m.m.	180
Robey ..	Four stroke	25	275	9½ in.	17 in.

The Petter engine relies for ignition on a combination of a low compression pressure (about 166 lb. per sq. in. at full load) with the effect of an uncooled dome in the cylinder head. Indiscriminate turbulence is caused by the separation of the main cylinder from the head by a large orifice. The spray is of the centrifugal type directed against the uncooled part of the head.

The Junkers engine sprays the fuel directly into the combustion space in a fan-shaped spray, and there is some organised turbulence due to the angle of the scavenge air ports.

The McLaren Benz engine makes use of a precombustion chamber, with its accompanying indiscriminate and very high turbulence.

The Robey engine relies on direct injection into the clearance space which communicates through a wide neck with the main cylinder. In addition the piston of this engine is fitted with a massive cast iron plate, bolted to, but insulated from it, and serving as a heat reservoir. The turbulence induced at the end of the compression stroke is comparatively low and of the indiscriminate type.

Fig. 1 shows the four designs of combustion space to scale, together with the position of the spray nozzles.

In the Petter and Junkers engines the spray nozzles are of the open type without moving parts beyond the pump except that in the Petter engine there is a small non-return valve near the nozzle. The McLaren Benz and Robey sprayers have spring loaded needle valves controlling the nozzles, the former being of

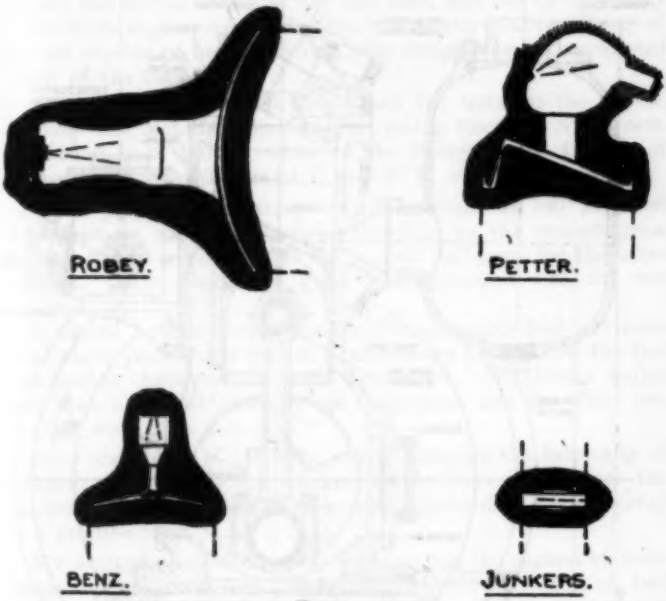


FIG. 1.

SECTIONAL DRAWINGS OF COMBUSTION CHAMBERS ALL DRAWN TO THE SAME SCALE.

the single hole type with the valve spindle projecting into the nozzle. The standard nozzle used for the Robey engine has two holes, 15/1000 in. diameter at an included angle of 30°, and this is interchangeable with two others, one being similar to the Benz design and the other having three 15/1000 in. diameter holes in a horizontal plane spaced with 15° between the central and the outer holes.

The Robey and Petter engines have variable stroke fuel pumps, the stroke being altered to suit the load. In the Petter engine

the static injection timing becomes slightly earlier as the load is reduced, while in the Robey engine the reverse is the case.

The Junkers and McLaren Benz engines work with constant stroke pumps, the volume of fuel delivered being varied according to the load by releasing a portion of fuel back to the suction line during the delivery stroke. The Junkers pump has a helical groove

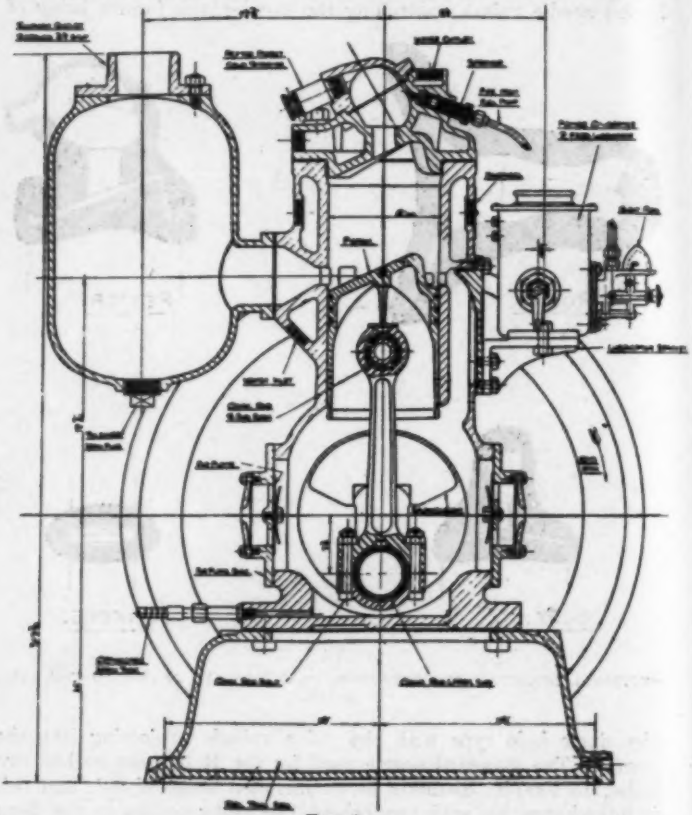


FIG. 2.
PETTER 8-HP. ENGINE.

in the pump plunger which is rotated according to governor setting and load requirements to open the pump chamber to the suction line. The Benz pump operates with a governor controlled spill

valve. In both pumps the static injection timing remains constant throughout the range of load, but actual injection of fuel into the cylinder will tend to become earlier as speed and pressure in cylinder diminish.

The very wide range covered by these various details of design should be borne in mind when the experimental results are compared, since it shows very clearly that the differences observed are largely due to the nature of the fuel used, and not to any easily controllable engine detail. In fact, the relative independence of certain aspects of fuel behaviour from design was an unexpected result of the research.

The lubricating oil used throughout the tests on the Petter, Junkers and McLaren Benz engines had a viscosity of 220 secs. (Redwood I) at 140° F., while on the Robey engine a grade of viscosity 110 secs. (Redwood I) at 140° F. was used.

Water jacket temperatures were maintained at 140° F. Fuel consumptions were measured by weighing to the nearest gram for the Robey engine and to the nearest half-gram for the other engines. Other details are given in conjunction with the test results.

It should be mentioned that the Robey engine had had more than three years' hard use on miscellaneous tests before the fuel combustion characteristics were determined. The Petter engine had been in almost constant use for a year, and the other two engines were quite new.

Since the object of the tests was to compare the behaviour of different fuels in various engines, rather than to compare the engines themselves, some of the experimental data are presented in a relative form.

For example, no attempt was made to run the engines at their maximum efficiency and consequently absolute values of fuel consumption per BHP Hour might convey a misleading impression of the comparative efficiencies of the different types of engine.

Fuel Consumptions.

Table II. gives the relative specific fuel consumptions (by weight) for the Robey, Junkers and Benz engines under various conditions, and also the mean relative specific consumptions for all the tests. The overall accuracy is of the order of 2 per cent. for a single test, this possible error being a combination of weighing, timing, brake reading, leakage measurement, and speed errors. The consumptions in each case are compared with that for fuel No. 1 under the same conditions of running.

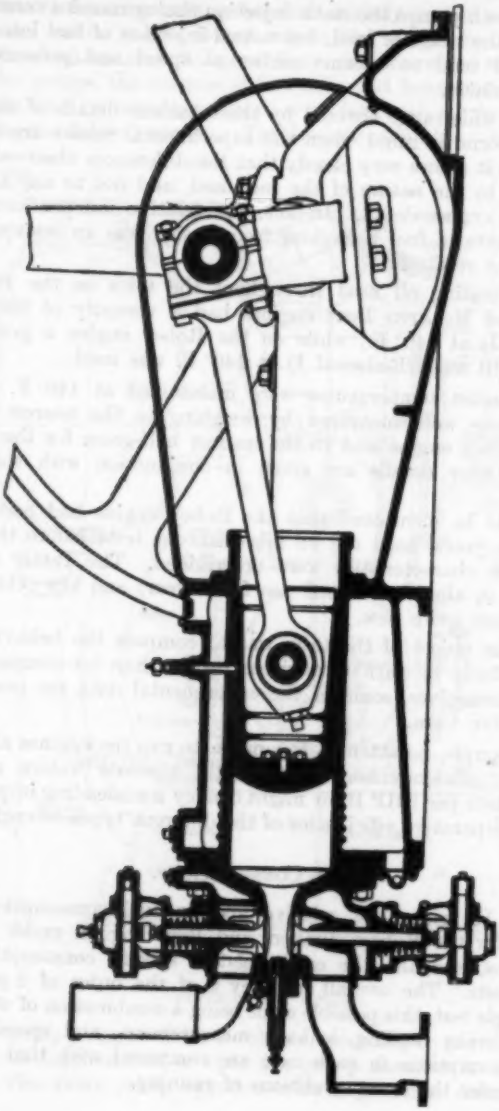


FIG. 3.

SECTION THROUGH ROBEY COLD START OIL ENGINE.

TABLE II.

Relative Consumptions.

(By Weight.)

Fuel No.	Robey Engine. Series. 1.	2.	3.	Junkers Engine. R.P.M. 1,000.	500.	Benz Engine. R.P.M. 990.	Mean of all Tests.
1. ..	1·00	1·00	1·00	1·00	1·00	1·00	1·00
2. ..	·98	1·01	1·01	1·02	·97	1·03	1·00
3. ..	·98	1·00	1·02	1·02	·99	1·04	1·01
4. ..	1·01	1·02	1·03	1·07	1·00	—	1·03
5. ..	·94	·97	·98	·98	1·03	1·04	1·01
6. ..	·95	·98	·99	1·00	1·03	1·00	·99
7. ..	1·01	·98	1·00	1·00	·99	1·02	1·00
8. ..	·97	·97	·99	·98	·97	1·01	·98
9. ..	1·01	1·01	1·02	1·02	1·01	1·03	1·02
10. ..	1·02	1·01	1·02	1·00	1·01	1·04	1·02
11. ..	1·01	·98	·99	1·01	1·01	—	1·00
12. ..	1·02	1·02	1·03	1·03	1·00	1·06	1·03
14. ..	·94	·94	·95	·96	1·02	1·02	·98

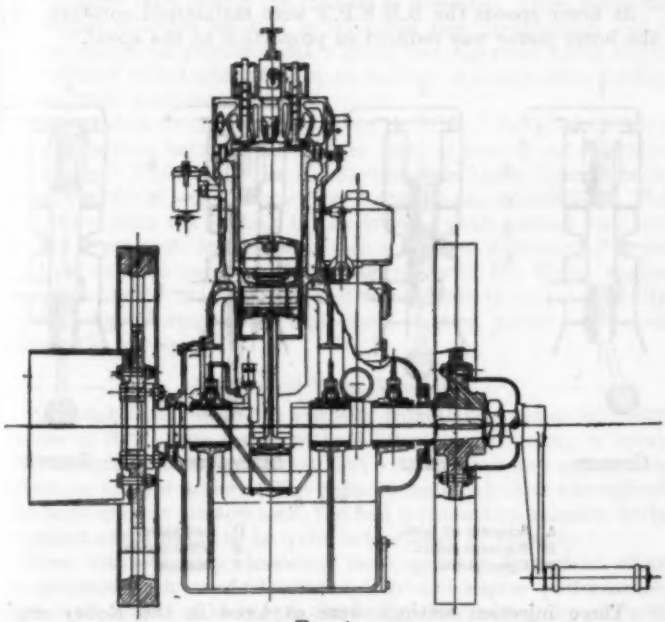


FIG. 4.

MCLAREN-BENZ AIRLESS INJECTION DIESEL ENGINE.

The use of kerosine limited the maximum load at which the Robey engine could be run on account of pump leakage, while the

loads selected for the high speed engines were determined by the maxima which it was considered advisable to carry continuously for the period occupied by the tests—a complete series occupied two runs of about eight hours' steady running each, and was thus much more severe than the widely varying load applied for road transport purposes where high mean pressures are rarely steadily maintained.

During the consumption tests and other tests the loads and speeds, unless otherwise stated, were as follows:—

Engine.	B.H.P.	R.P.M.	B.M.E.P. lb./sq. in.
Robey	20 ..	275 ..	48·0
McLaren Benz	11·5 ..	1000 ..	67·5
Junkers	6·9 ..	1000 ..	64·2

At lower speeds the B.M.E.P.'s were maintained constant, i.e., the horse power was reduced in proportion to the speed.

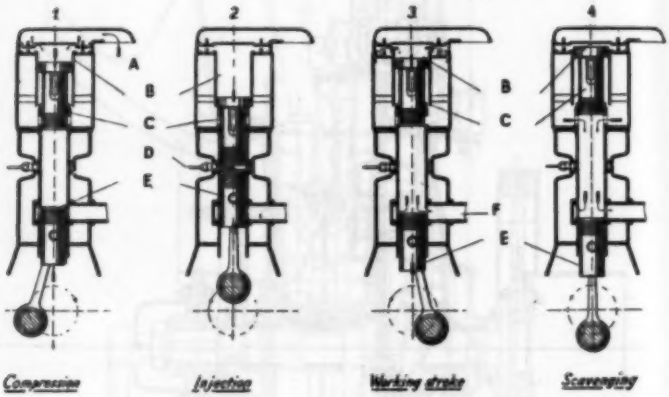


FIG. 5.

A Scavenge air inlet.
B Scavenge pump.
C Upper piston.
D Fuel valve.
E Lower piston.
F Exhaust.

Three injection settings were explored in the Robey engine and are referred to as Series 1, Series 2 and Series 3. These correspond with static beginning of fuel pump delivery at full governor position of 28°, 33° and 39° before T.D.C. respectively. Fuel compressibility in a long delivery pipe line and slip past the suction

valve at the beginning of stroke accounted for a loss of approximately 9° of crank angle between the beginning of pump stroke and the opening of the spray valve. The Junkers pump plunger closed the suction port at 17° before the end of compression, the actual delivery into the cylinder commencing at 12° before the end of compression at 1,000 r.p.m., and 14° before the end of compression at 500 r.p.m. The Benz pump commenced delivery 12° before the end of compression and injection commenced at 7° to 9° before t.d.c.

A 6° alteration of fuel cam timing in the Robey engine was quite sufficient to cover the best settings for all fuels and generally the best consumptions were all obtained within a range of timing of 3°. No timing adjustment was attempted on the Junkers or Benz engines, but it does not appear probable that appreciable improvement in consumptions of any individual fuel could be made without at the same time raising the maximum pressure. Thus, assuming an earlier injection resulted in improved fuel consumption and a higher maximum pressure with a given fuel, the same result might be obtained with another fuel by an increase of compression leading to the same maximum pressure.

It is evident from the values given in Table 2 that there is very little difference between the various fuels as regards consumption by weight. Fuels 4, 9, 10 and 12 have slightly higher consumptions than Fuel No. 1, while Fuels Nos. 8 and 14 are a little less. The difference from the highest to the lowest (mean values) does not exceed 5 per cent. as compared with a greatest difference of 3 per cent. in calorific values. The consumptions of the Robey engine are probably the most reliable, as it was difficult to keep a perfectly uniform load output in the high speed engines, particularly when running at low speeds.

Effect of Fuel Viscosity.

Although fuels ranging in viscosity from 0·0204 poises to 0·5659 poises at 70°F. were tested without alteration to timing or spray valves, there was no indication that viscosity has any appreciable effect on sprayer action. The exhaust remained clear throughout the tests and, as already seen, the fuel consumption remains fairly constant and appears to be quite independent of viscosity.

Fuel viscosity may, however, have quite an important effect in practice both on fuel consumption and engine performance, due to the effects of leakage in the fuel system from pump plungers and fuel valve spindles.

The Robey engine having been in use for more than three years using various grades of fuel, the pump and valve arrangements were sufficiently worn to be typical of the condition of an engine

fuel system after considerable use. Arrangements were made to collect and measure all fuel leakage during each test, and the resulting measurements are plotted on Fig. 6.

It will be seen that the leakage rises rapidly as the viscosity falls, and that the reciprocal of leakage (by weight) plotted against kinematic viscosity follows a straight line law, except at very low viscosity.

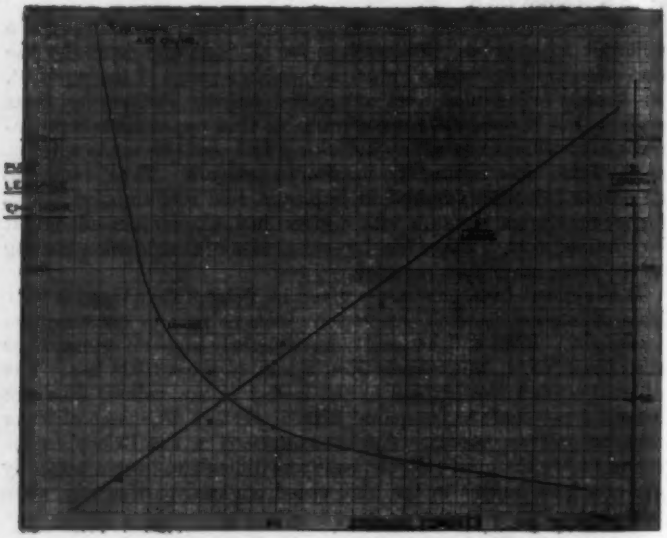


Fig. 6.

FUEL PUMP LEAKAGE CURVES.

When using fuels of very low viscosity in conjunction with worn pumps and valves, the fuel consumption may easily be increased by as much as 10 per cent. The recovery of all fuel leakages is not easily arranged and in some cases is impossible as, for instance, in an air injection engine where any needle valve leakage will be blown away. A reduction in output will also occur if the fuel pump arrangements are such that it is impossible to provide the extra fuel necessary to cover the leakage losses. Where these losses become excessive through badly worn ports, sprayer action will no doubt also be affected, leading to a further fall off in output and efficiency.

In the Junkers and Benz engines the pumps were quite new, and records of fuel pressures in the delivery lines together with the actual timings showed that the leakage was negligible, and in the case of the Benz running on kerosine did not amount to more than 1 per cent. of the total consumption.

The general conclusion from the consumption and leakage tests is that, as in the case of petrol engines, there are no marked differences between fuels in respect of fuel consumptions obtainable for a given maximum cylinder pressure. Reported large differences between fuels are more likely to be due to uncollected or uncollectable leakages, which will vary with the viscosity, or to very bad leakage affecting sprayer action.

The Process of Combustion.

Ricardo has pointed out that the process of combustion in a Diesel engine may be divided into three more or less distinct stages.

(*a*) The delay period between the beginning of injection into the cylinder and the commencement of pressure rise above the compression line.

(*b*) A period of rapid and almost uncontrollable combustion during which the fuel already injected burns.

(*c*) A further period during which the remainder of the fuel ignites at the nozzle and burnt at a rate controlled by the pump and nozzle.

We have used the following terms for the various stages of the combustion period.

"Delay Period" signifies the period between injection and the beginning of pressure rise, and is more definitely specified as "Delay Angle" when expressed in terms of degrees of crank angle, and "Delay Time" when expressed as an absolute time. The unit of time adopted is the microsecond.

"Break Away" is used to denote the point at which the combustion line leaves the compression line.

Instead of the term "Detonation" we prefer to use the words "Combustion Shock," since "detonation" has a definite physical meaning and may not, in the true sense, occur in engines.

Piston type indicators, however light the moving parts and however stiff the controlling spring, are practically useless for an analysis of the combustion process. They increase the delay angle at quite slow engine speeds (150 r.p.m.) and exaggerate the maximum pressure, the error depending to some extent on the degree of combustion shock, but also on the type of break away.

A Farnboro Indicator was used for all the diagrams given, the electrical circuit being modified for operating from a 100-volt D.C.

supply. The disc valve unit was flexibly connected to the body of the indicator to prevent missing due to stray contacts between the stem of the disc valve and the surrounding sleeve. Several hundreds of diagrams have been taken and the accuracy of repeats is remarkable, it being an exception to find a difference of more than 1° of crank angle between two diagrams for, say, the point of break away in a given engine with the same general conditions of injection and loading. In this respect the results are of a higher order of accuracy than individual consumption tests. The greatest errors occurred with the smoothest burning fuels, owing to the break away being almost tangential to the compression line.

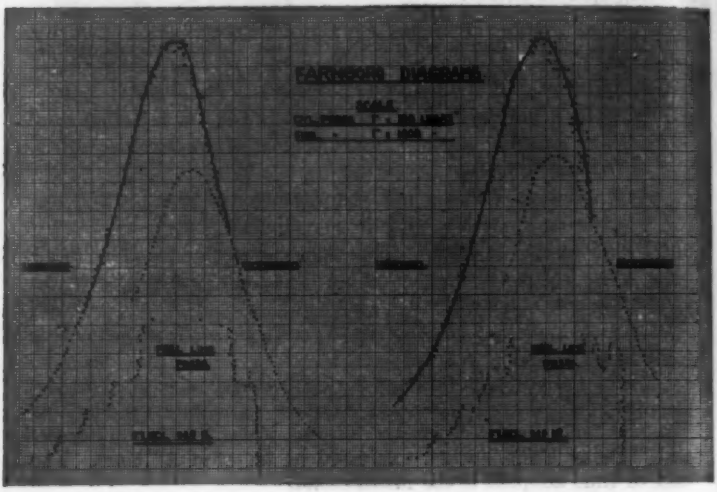


FIG. 7.

FARNBORO DIAGRAMS FROM FUELS 5 AND 12 TO SHOW DIFFERENCES IN REGULARITY OF BURNING.

Fig. 7 shows Farnboro diagrams taken from the Robey engine from Fuels Nos. 5 and 12, these giving the smoothest and roughest running of the petroleum fuels used on this engine. It will be noticed that there are very few stray points in the first card, and that the second shows a band of punctures starting shortly after break away. This difference occurs between other fuels and was found to be typical, a more erratic diagram being obtained from the fuels with a wide distillation range than from those with a narrow range in the same series, and the strays increasing as the aromatic end of the fuel range is approached.

Fig. 8 shows diagrams taken during Series 2 of the consumption test on the Robey engine. Fuel No. 5 was the smoothest as regards freedom from combustion shock, and No. 2 was almost its equal. Fuel No. 13—creosote—gave a very pronounced and alarming shock. Fuels 10 and 12 both gave marked shock, fuel 12 producing slightly more pronounced shock than No. 10.

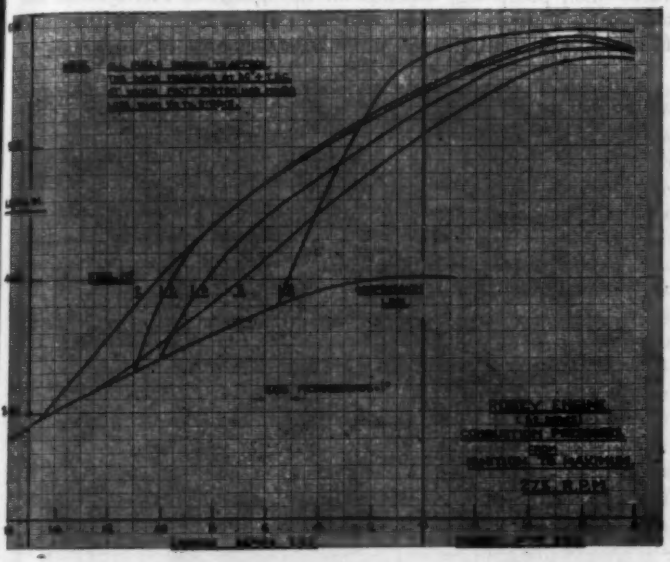


FIG. 8.

COMBUSTION LINE DIAGRAMS FOR FUELS 2, 5, 10, 12 AND 13 TAKEN FROM ROBEY ENGINE.

With regard to the remaining fuels, Nos. 1, 4, 6 and 7 all gave diagrams lying between Nos. 2 and 5 for rate and time of pressure rise. No. 3 agreed fairly closely with No. 5; No. 8 was rather steeper than No. 2 at the start, but the initial rate of pressure rise was not maintained as long as in the case of No. 2; No. 9 approximated to No. 10, and No. 11 to No. 12. The curve for No. 14 was steeper than No. 2, but less steep than No. 10.

Examination of these and other results suggest that it is not only the initial rate of pressure rise per degree of crank angle that determines shock, but also the time during which the highest rate of pressure rise is applied. Any advance of the static injection angle led to higher maximum pressures and greater shock, although, in

some cases, the angle between the compression line and the combustion line at the point of break away was decreased.

In order to determine the precise point at which the fuel entered the cylinder, an indicator was fitted to the end of the needle valve, and in this way the delay angle could be measured for each test. The delay between the beginning of pump stroke and lift of spray valve—i.e., pump lag, depends on the design of fuel system and the speed of engine. It amounted to about 9° in the Robey, 5° in the Junkers, and 3° to 5° in the Benz engine at full speed.

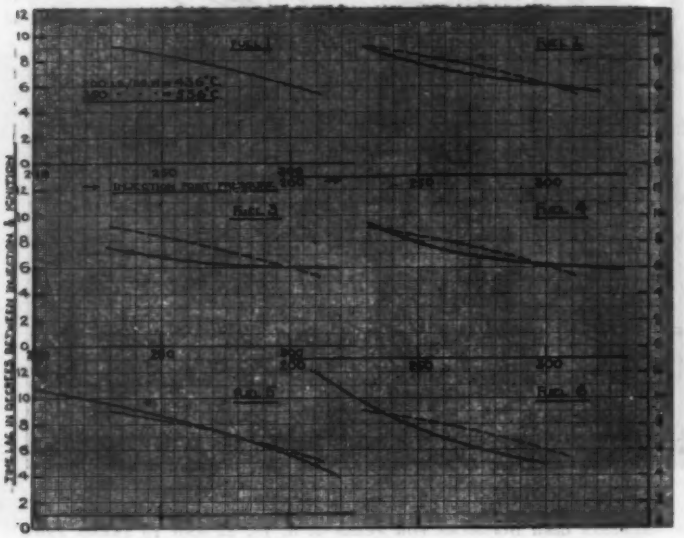


FIG. 9.

CURVES OF DELAY ANGLES PLOTTED AGAINST PRESSURE AT MOMENT OF SPRAY VALVE LIFT FOR ROBEY ENGINE. FUELS 1 TO 6.

Figs. 9 to 11 show the relation between the delay angle from the moment of lift of the spray valve and the beginning of pressure rise for each fuel used in the Robey engine for a range of three static settings of the injection timing. The dynamic setting varied from diagram to diagram by ± 2°, owing to mutual effects of governor on effective cam lift and on pump timing, and also due to differences in fuel leakage. It was also not possible to return precisely to the same static setting for repeat diagrams, and the curves, in some instances, are based on as many as eight points.

It will be seen that each fuel has its own characteristics as regards delay angle for different cylinder pressures (and therefore temperatures) at the moment of injection. The curve for Fuel No. 1 has been repeated on each diagram for purposes of comparison. In general the delay angle decreases as the injection is retarded owing to the higher temperature at the moment of injection. This higher temperature causes a higher velocity in the initial reaction preceding inflammation. A marked exception, however, occurs in the case of kerosine where the delay angle increases with later injection. This

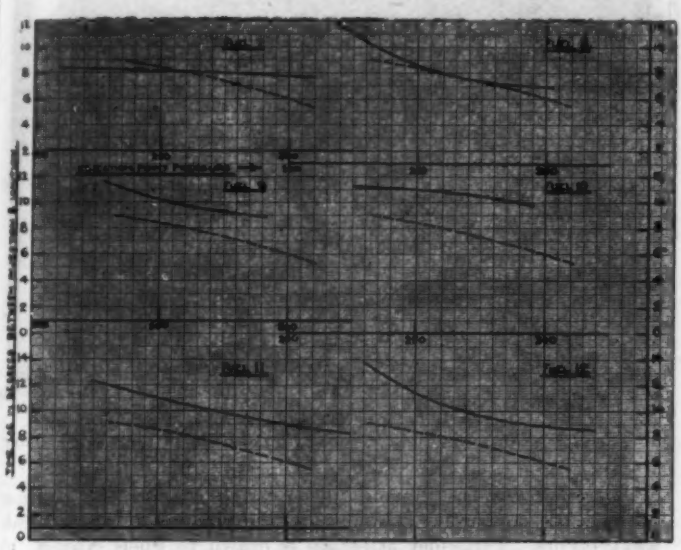


FIG. 10.

CURVES OF DELAY ANGLES PLOTTED AGAINST PRESSURE AT MOMENT OF SPRAY VALVE LIFT FOR ROBEY ENGINE. FUELS 7 TO 12.

may be due to the fact that a spray of kerosine penetrates without appreciable spread and that ignition occurs when the spray reaches the combustion chamber wall in the Robey engine. The higher the pressure in the cylinder at injection, the slower the time of penetration and hence the greater the delay angle. In all other cases the combustion probably commences in the broken front of the spray before it reaches the metal of the combustion head.

Subsequent tests indicated generally that fuels giving a longer delay angle than Fuel No. 1 (i.e., having curves placed higher on Figs. 9 to 12) gave greater combustion shock and *vice versa*.

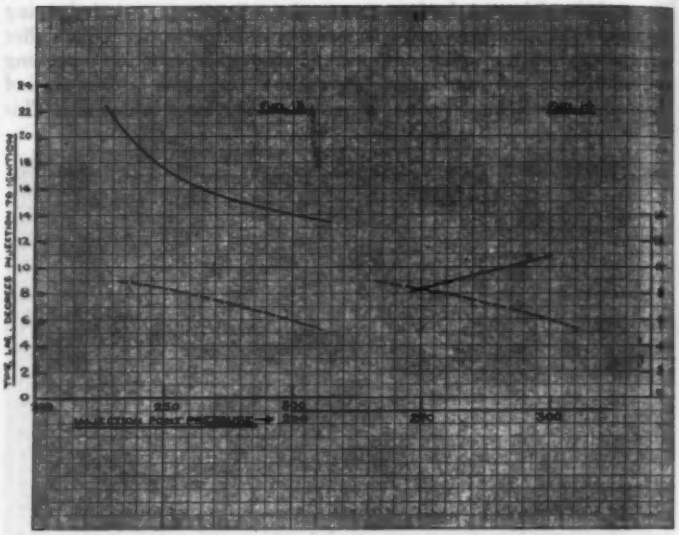


FIG. 11.

CURVES OF DELAY ANGLES PLOTTED AGAINST PRESSURE AT MOMENT OF SPRAY VALVE LIFT FOR ROBEY ENGINE. FUELS 13 AND 14.

Fig. 12 shows the same data converted to give the relation between the pressure at injection and the pressure at which break away occurs. Particular attention is drawn to Fuels Nos. 8, 10 and 12. The first of these is tangential to No. 1 at one point but rises quickly at each side of this point. Curves 10 and 12 show a steep crossing angle. This behaviour suggests that under some conditions Fuel No. 8 might behave in a similar manner to No. 1 as regards shock, while in others it might give considerable shock. The crossing of curves 10 and 12 suggests that these fuels might be placed in different orders as regards behaviour under different operating conditions. These indications were actually borne out in later tests on the high speed engines. Fuels Nos. 1 to 8 were found not to give any objectionable shock in the Robey engine and Fuel No. 9 was reasonably good, but fuels Nos. 10, 11 and 12 were all bumpy, and fuel No. 13 gave violent shock.

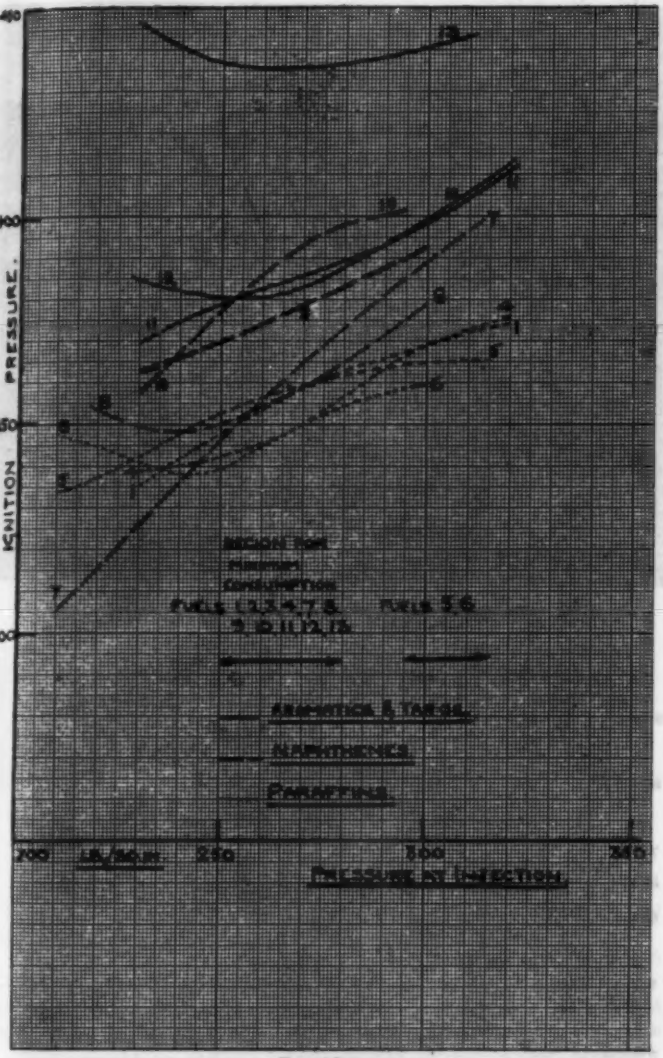


FIG. 12.

CURVE OF INJECTION PRESSURE PLOTTED AGAINST IGNITION POINT PRESSURE. BOBEY ENGINE.

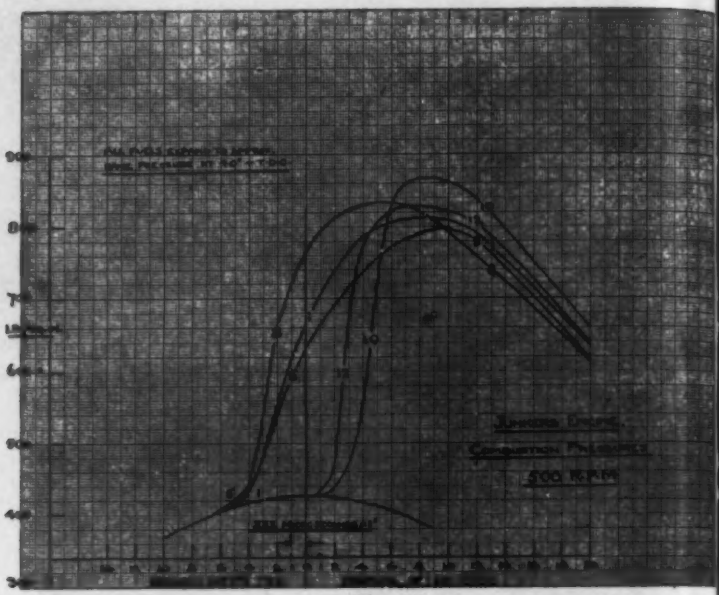


FIG. 13.

COMBUSTION LINE DIAGRAMS FROM JUNKERS ENGINE AT 1,000 R.P.M.

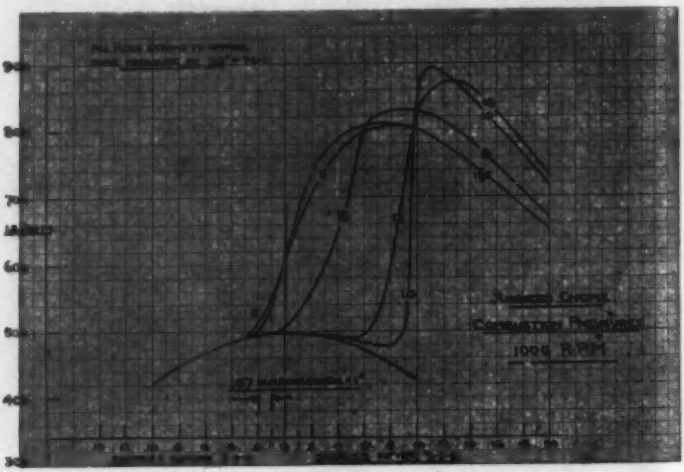


FIG. 14.

COMBUSTION LINE DIAGRAMS FROM JUNKERS ENGINE AT 500 R.P.M.

There does not seem to be any definite relation between the delay angle and either self-ignition temperature as measured in a Moore apparatus or ease of starting.

Figs. 13 at 14 show the Farnboro diagrams taken from the Junkers engine at 1000 r.p.m. and 500 r.p.m. respectively. Fuels Nos. 1 to 8 and No. 14 were all smooth running at 1000 r.p.m. and at 6·9 b.h.p., while Nos. 9, 10, 11 and 12 gave some shock. Marked shock was noticeable for fuels 9, 10, 11 and 12 at 500 r.p.m. It is clear from these diagrams that combustion shock is not conditioned

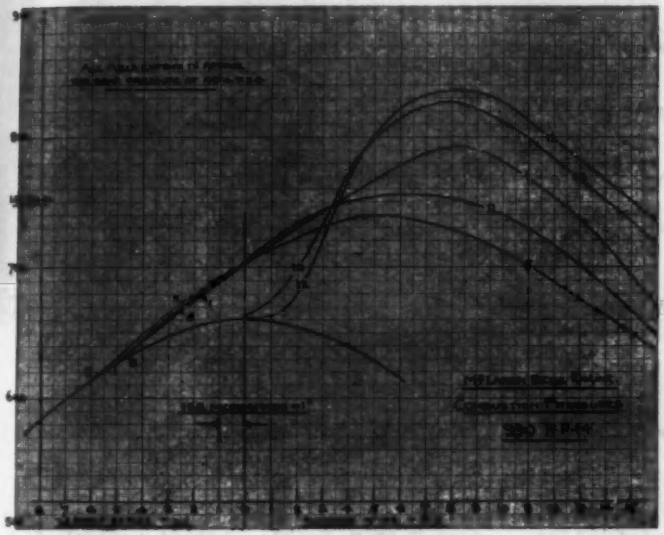


FIG. 15.

COMBUSTION LINE DIAGRAMS FROM BENZ ENGINE AT 990 R.P.M.

solely by maximum rate of pressure rise, but is also related to engine design and running speed even for a constant rate of pressure rise per degree of crank angle.

Attention is drawn to the fact that the diagram for fuel No. 8 is displaced at slow speeds to a marked extent.

Diagrams from the Benz engine at 990 r.p.m. and 11.5 h.p. and 590 r.p.m. at same torque are shown in Figs. 15 and 16. The rates of pressure rise in the main cylinder are much less than those for the Junkers engine, but the combustion shock was more marked.

Fuels 9, 10 and 12 gave slight shock at 990 r.p.m., and there was heavy shock from fuels 8, 10, 11 and 12 at 800 r.p.m. Shock from fuel No. 12 was particularly pronounced below 700 r.p.m.

It should be noted be noted that fuels Nos. 10 and 12 are reversed in order as regards delay angle on this engine as compared with the Junkers engine.

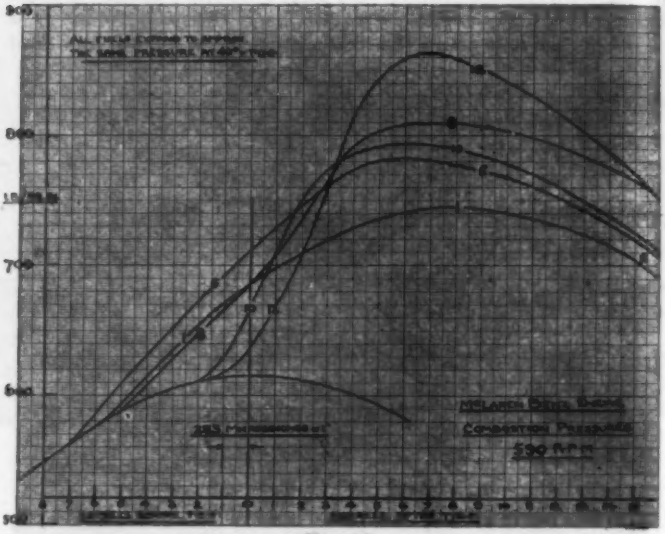


FIG. 16.

COMBUSTION LINE DIAGRAMS FROM BENZ ENGINE AT 590 R.P.M.

The results from the various indicator diagrams have been analysed in two ways. Table 3 gives the relation between the fuels as regards delay angles, the values in brackets being the *differences* for a given set of conditions on a given engine from fuel No. 1. Table 4 gives the delay times in micro seconds between the fuels on each engine for the various conditions.

The delay angle for the Junkers engine was measured by means of a fuel line indicator and since this fitting is liable to disturb the injection timing when the fuel used per stroke is very small, the angles were determined relatively in a separate series of tests and then applied to diagrams taken without the fuel line indicator in place.

It will be noticed that the Junkers engine with open type nozzle has larger delay angles than the other engines with spring loaded spray valves. This effect is possibly due to the fact that with the

open type nozzle the fuel enters the cylinder as soon as the fuel line pressure just exceeds the compression pressure in the cylinder, whereas with a spring loaded spray valve the fuel is suddenly injected at a pressure of two or three times the pressure in the cylinder at the moment of injection.

TABLE 3.

Delay Angles.

Fuel. No.	Robey Engine. Series.			Junkers Engine. R.P.M.		Benz Engine. R.P.M.	
	1.	2.	3.	1,000.	500.	990.	590.
1.	6°	8°	9°	10°	8°	2°	2°
2.	6(0)	7(−1)	9(0)	9(−1)	9(+1)	4(+2)	2(0)
3.	6(0)	6½(−1½)	7½(−1½)	9(−1)	8(0)	4(+2)	—
4.	6(0)	7(−1)	9½(+½)	9(−1)	7(−1)	—	—
5.	5½(−½)	8(0)	9½(+½)	9½(−½)	7(−1)	1(−1)	1(−1)
6.	5(−1)	7(−1)	9½(+½)	11(+1)	8(0)	3(+1)	—
7.	8(+2)	8(0)	8(−1)	11(+1)	9(+1)	3(+1)	—
8.	7(+1)	8(0)	10½(+1½)	10½(+½)	9(+1)	3(+1)	3(+1)
9.	9(+3)	10(+2)	11½(+2½)	15(+5)	14(+6)	7(+5)	5(+3)
10.	9½(+3½)	11(+3)	11(+2)	16(+6)	14(+6)	6(+4)	6(+4)
11.	9(+3)	10½(+2½)	12(+3)	12(+2)	11(+3)	7(+5)	—
12.	9(+3)	10½(+2½)	14(+5)	15(+5)	14(+6)	7(+5)	6(+4)
13.	14(+8)	16½(+8½)	21½(+11½)	—	—	—	—
14.	11(+5)	9(+1)	7½(−1½)	9(−1)	8(0)	1(−1)	—

Figures in brackets ( ) show the Increase or Decrease in Delay Angle as compared with Fuel. 1.

The delay angle in the Benz engine is so small for fuel No. 5 that it is masked by experimental errors of measurement. This small delay angle is ascribed to the extremely high degree of turbulence in the precombustion chamber.

TABLE 4.

Delay Times.

(*Micro seconds.*)

Fuel No.	Robey Engine. Series.			Junkers Engine. R.P.M.		Benz Engine. R.P.M.	
	1.	2.	3.	1,000.	500.	990.	590.
1.	3,650	4,850	5,450	1,650	2,650	350	550
2.	3,650	4,250	5,450	1,500	3,000	650	1,100
3.	3,650	3,950	4,550	1,500	2,650	650	—
4.	3,650	4,250	5,750	1,500	2,350	—	—
5.	3,350	4,850	5,750	1,600	2,350	170	280
6.	3,050	4,250	5,750	1,850	2,650	500	—
7.	4,850	4,850	4,850	1,850	3,000	500	—
8.	4,250	6,050	6,350	1,750	3,000	500	850
9.	5,450	6,050	7,000	2,500	4,650	1,200	1,100
10.	5,750	6,650	6,650	2,650	4,650	1,000	1,700
11.	5,450	6,350	7,300	2,000	3,650	1,200	—
12.	5,450	6,350	8,500	2,500	4,650	1,200	1,700
13.	8,500	10,000	13,000	—	—	—	—
14.	6,650	5,450	4,550	1,500	2,650	170	—

The differences in delay angles between the various fuels are, with minor exceptions, already indicated by Fig. 8 in very good general agreement between one engine and another and between the different speeds.

Fig. 17 shows diagrams taken at 990 r.p.m. and 11·5 b.h.p. for fuels Nos. 1 and 12, the diagrams being taken from the main and precombustion chamber. The curves cannot be compared directly with those on Fig. 15, as the addition of an indicating unit to the precombustion chamber increased the volume and thus altered the compression ratio, increased the delay angle and modified the pressure rise after ignition. The general characteristics of the two

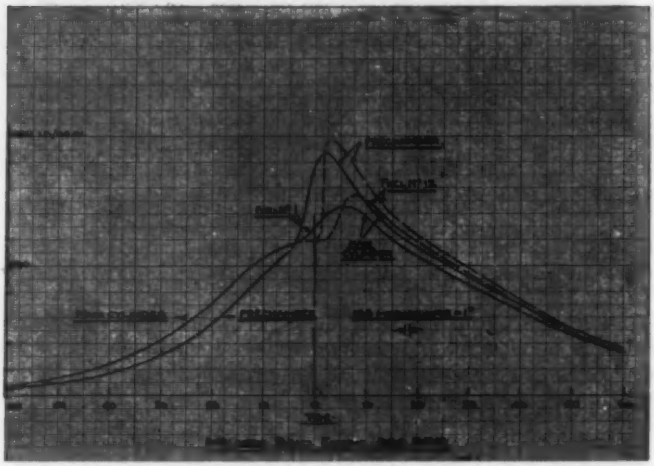


FIG. 17.

COMBINED DIAGRAMS OF MAIN CYLINDER, PRECHAMBER, FUEL LINE PRESSURE AND FUEL VALVE LIFT FROM BENZ ENGINE AT 1,000 R.P.M. FOR FUELS 1 AND 12.

fuels are, however, unaltered. The behaviour of fuel No. 12 in the precombustion chamber is very violent and erratic, and there are indications that the disc valve bounces on its seat under these conditions.

It is dangerous to attempt to generalise too much regarding the combustion process from the data obtained. In both the Robey and the Junkers engines the delay angle was nearly constant for any fuel over the speed ranges examined, i.e., from 150 to 275 and from 500 to 1000 r.p.m. respectively. Thus the delay *times* are greater the lower the speed owing to the decreased turbulence. It should be noted that the delay angles do not, in all cases, indicate the angle at which the rate of pressure rise becomes rapid. Thus fuels Nos. 9, 10 and 12 begin to burn very slowly in the high-speed

engines. It is evident that, from the data available, it is not safe to say more than that, in the majority of the tests, the relative behaviour of two fuels as regards rates of pressure rise and delay

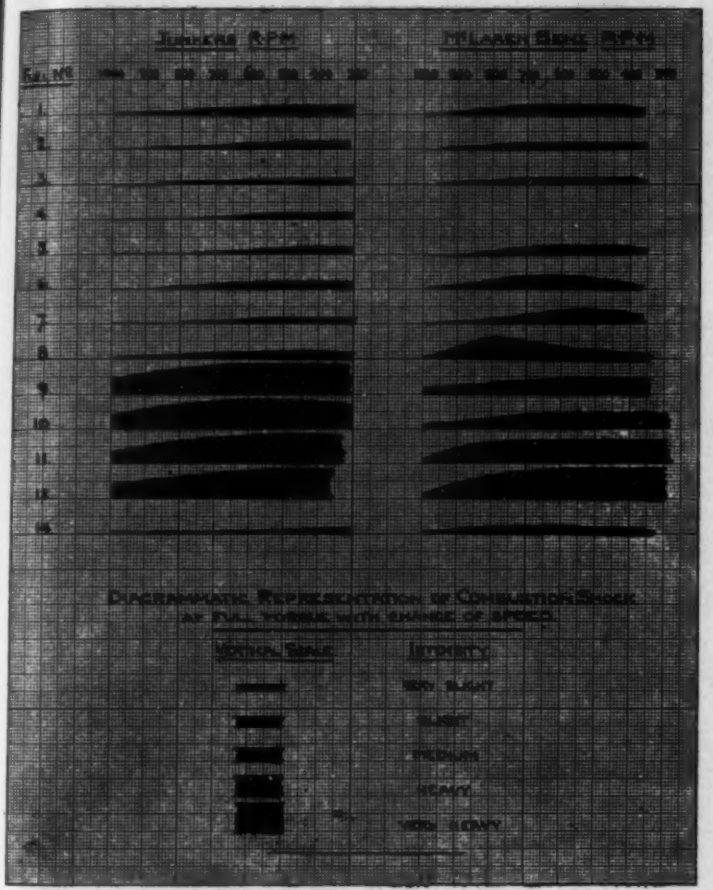


FIG. 18.

DIAGRAMS OF SHOCK AUDIBILITY.

angle will be reproduced in an engine of an entirely different design, and that the longer the delay angle and the greater the subsequent rate of pressure rise, the greater the risk of combustion shock.

Following the examination of each fuel by means of indicator diagrams, tests were made on the Junkers and Benz engines by operators who had not examined the diagrams. The object of these tests was to compare the combustion shock from each fuel with the engines running at maximum torque over a speed range downwards from 1000 r.p.m. to that at which shock decreased due to imperfect sprayer and pump action. The results of these tests are shown diagrammatically in Fig. 18. The height of the shaded portion at each speed represents the intensity of shock, and these audibility diagrams may be used for reference in connection with the tables of delay angles, and the various indicator cards.

Ease of Starting.

Ease of hand starting could be noted roughly on the Petter engine, and tests on this plant may be taken as typical of what is likely to occur in engines which rely for starting on a heated surface. The relative position of a series of fuels as regards starting in this type of machine is not necessarily the same as for compression ignition engines, owing to the difference between injection into a hot gas and spraying on to a hot surface. In order to examine the behaviour with direct injection into hot air, the Benz engine, usually started with a glowing fuse or electrically-heated wire, was fitted with an inlet air heater and a steam heated water supply circulated at a speed sufficient to maintain substantially the same temperature throughout the jacket. The engine was motored at 300 r.p.m. and the air and jacket temperatures raised to about 50° C. After sufficient time had elapsed for all the working parts to attain a steady temperature the compression easer was put into the full compression position and the vent valve of the fuel pump immediately closed. In all cases except that of fuel No. 13 (low temperature tar oil) the engine fired immediately. The fuel valve was at once vented again and the engine decompressed and the temperatures of both jacket and air reduced by 5° C. and the test repeated until there was hesitation before firing occurred. The temperature was then raised 5° and taken down in 1° stages until hesitation occurred. In this way it was possible to determine starting temperatures to within 1° C. without difficulty. Table 5 gives details of the relative ease of starting for the Petter engine, and also the air and jacket temperatures necessary for certain starting in the Benz engine. Self-ignition temperatures determined in a Moore apparatus with the oxygen supply heated to bomb temperature are also included.

Fuels 9, 10 and 13 could not be used in the Petter engine. The first two required constant use of the blowlamp and no degree of heating sufficed to make the third burn. The Benz starting test

failed with 100° C. jacket and air temperature on fuel No. 13 and the Robey engine would only run on this oil, and then badly if it was started and warmed up on another fuel.

TABLE 5.

Starting Tests.

Fuel No.	Petter Engine.	Benz Engine. Air and Jacket Temp. °C.	S.I.T. in Oxygen (Moore) °C.
1.	Under 6 turns.	31	262
2.	„	28	262
3.	Under 25 turns.	23	262
4.	Under 6 turns.	35	265
5.	„	27	268
6.	„	33	263
7.	„	29	262
8.	„	27	262
9.	—	37	279
10.	—	40	272
11.	Over 25 turns.	33	288
12.	Under 25 turns.	38	273
13.	—	Above 100.	Above 520
14.	Under 6 turns.	32	259

It is obvious that spontaneous ignition temperatures determined in the usual manner are no practical guide to ease of starting in an engine. A fuel which will start at 20° to 25° (Benz values) has very obvious advantages over one which requires a temperature of 30° to 40° C. The difference is such that, in the first case, restarting is possible after a short involuntary stoppage, while in the second it will be necessary to use a fuse or the electric starting element again. Engines which rely on direct compression without an auxiliary ignition device may be in an even worse position if a change of fuel raises the minimum starting temperature to a value a few degrees above winter morning conditions.

An examination of self-ignition temperatures in a bomb at atmospheric pressure in air and also in oxygen, and an extension of the test to higher pressures up to those obtaining in engines, has been carried out by Tausz and Schulte (see Nat. Advisory Committee for Aeronautics. Technical Memos. Nos. 483 and 484 for translations) who showed that the S.I.T. of the paraffin falls with rise of pressure, but by different amounts for different fuels, and that compounds of the aromatic series might behave in the opposite way, the ignition temperature rising with increase of pressure. They suggest that in the case of the paraffins, and after a longer time interval the naphthenes, there is a surface breakdown resulting in the formation of peroxides with very low spontaneous ignition temperatures from which the combustion starts. The aromatics, on the other hand, depend for ignition on breakdown to a point where hydrogen is evolved, hence the much

higher temperatures required and the longer delay time. These investigators also showed that blends of the paraffins and aromatics did not necessarily have S.I.T.'s lower than the latter until as much as 50 per cent. of the former was added. Sass (National Advisory Committee for Aeronautics, Memo. No. 482), examining the work of Tausz and Schulte and others, concludes that vaporisation plays no part in either the ignition or combustion in Diesel engines, and that volatility is, therefore, no criterion of behaviour in either respect. These conclusions are entirely supported by our tests, thus fuel No. 12 is rather better as regards its distillation range than fuel No. 3 and yet the starting temperatures (Benz) differ by 15° C. and, as has been shown, the combustion proceeds much more easily in the latter fuel. Fuels Nos. 5 and 10 have almost identical distillation ranges, and are almost at the extremes of behaviour as regards both starting and combustion.

Effects of Dopes.

Many attempts have been made to improve the delay time and to reduce the combustion shock of certain fuels by the addition of suitable dopes. The essential characteristic of such materials is that they shall have a low self-ignition temperature at the pressure of injection, and while we have not been able to make an exhaustive research, a few substances have been examined which, although not commercially practicable, are known to be effective. Amyl nitrite, acetaldehyde, and benzaldehyde may be employed for research purposes, although the cost of the first named, the low boiling point of the second and the rapid decomposition of the third prevent their practical use.

Fig. 19 shows the alteration in Benz engine to delay angle and to the shape of the combustion line when as much as 5 per cent. amyl nitrite (a pronounced pro-knock in petrol) is added to fuels Nos. 1 and 12. In both cases the delay angle is reduced by nearly a degree of crank angle, maximum pressures are reduced, especially for fuel No. 12 and the combustion process is slightly extended. Fuel No. 12 still shows a more rapid rate of pressure rise with 5 per cent. dope than that of fuel No. 1 without dope, and hence will give running roughness earlier as speed is reduced in a high speed engine of a type liable to bumpiness.

Experiments on the Robey engine with 5 per cent. amyl nitrite in fuel No. 1 showed that this dope reduced the length of the initial part of the combustion line immediately following the break away, and also decreased the angle between the compression line and the combustion line. Five per cent. acetaldehyde had a much more marked effect, the combustion line break away being almost imperceptible.

When the same dopes were added to fuel No. 12 the relative effects were reversed, amyl nitrite having the better action, while that of acetaldehyde was not pronounced. In neither case did the doping of fuel No. 12 lead to the smoothness of running associated with fuel No. 1 with the same amount of dope.

Addition of water to a fuel has practically no effect on the combustion line, nor is it likely that it should. Combustion is independent of volatility and it cannot be expected that the much

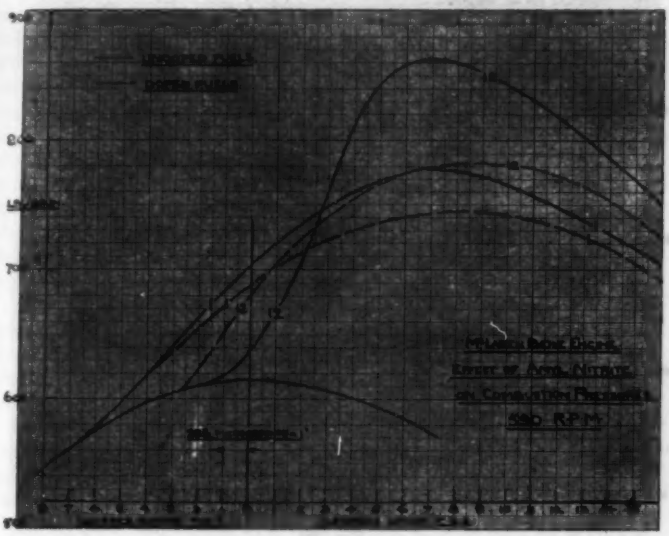


FIG. 19.

EFFECT OF AMYL NITRITE ON FUELS 1 AND 12 ON BENZ ENGINE.

more stable water drops will be vaporised during the earliest part of the combustion process. The presence of water may, due to the persistence of the droplets in liquid form, have a very bad effect on various engine parts. In the case of the Petter engine, 5 per cent. of water added to fuel 4 reduced a very heavy carbon formation materially, and an examination of the bulb after a test on the mixture shows that an intense scouring action had occurred in the direct path of the spray. Larger engines have been opened out after running on fuel containing water, and portions of the pistons have been found to be deeply pitted. This again is probably due

entirely to the abrasive action of water droplets moving at a very high velocity, and not affected by the prevailing temperatures until after they reach the metal surfaces. Such effects are, of course, confined to what can happen at the beginning of the firing stroke. Later, the water is changed to steam and passes out with the exhaust which is reduced in temperature.

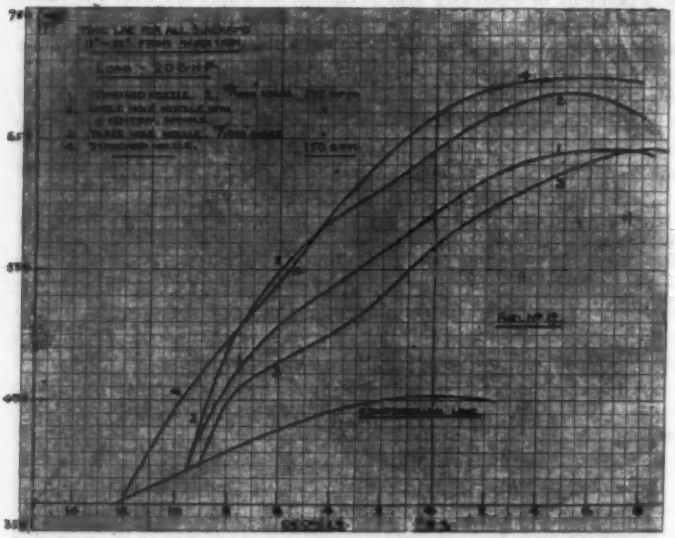


FIG. 20.

EFFECT OF CHANGE OF NOZZLE AND CHANGE OF SPEED ON ROBEY ENGINE.

Alterations to Spray Nozzle and Speed on the Robey Engine.—A partial examination of the effect of alteration of spray nozzle was made on the Robey engine in order to determine whether increased atomisation of spray and decreased rate of combustion would reduce the shock of Fuel No. 12.

Increased atomisation was obtained by using a nozzle with a single hole and a central spindle, so that the fuel was ejected in the form of a wide angle cone in a very finely divided form. Fig. 20 shows the alteration in the diagram, curve 1 being for the standard two-hole nozzle and curve 2 that for the single hole nozzle.

The finer division of the fuel led to much more rapid pressure rise in the early stages of combustion, but this was followed by a lag due to increased general resistance and the exhaust was smoky. The combustion shock was definitely worse than with the standard nozzle. When a three-hole spray was substituted with the holes at 15° the interference between the three jets and the coarser atomisation made an improvement in combustion shock (curve 3). The initial rate of pressure rise is seen to be the same as for nozzle 1, but the rate of pressure rise falls away early and combustion is delayed. The exhaust was clear in this test, but the diagram suggests that this method of control is only likely to be applicable to engines running at a fixed speed. This is further indicated by curves 1 and 4, both taken with the standard spray nozzle but at speeds of 275 and 150 r.p.m. respectively. It is seen that reduction of speed has little or no effect on the initial rate of pressure rise, but that it materially increases the length of the steepest part of the combustion line, and therefore increases the tendency to combustion shock as the speed falls, so that while an adjustment such as is obtained by the use of the three-hole nozzle might be sufficient to reduce shock at a given speed, it would lead to a smoky exhaust at higher speeds and to still allow shock at lower speeds.

A paper of this description would be incomplete without further reference to the behaviour of motor fuels as regards pinking in spark ignition engines, and the relation between such fuels and those which give the most pronounced combustion shock in compression ignition engines.

In recent years a large number of pure volatile hydrocarbons have been tested for anti-knock value in suitable petrol engines, and definite relations established between tendency to knock and the chemical composition and structures of the molecule. It is, however, quite impossible to give anything approaching an accurate estimate of the knocking tendency of motor spirit from a chemical examination.

The problem with regard to heavy oils is much more complex, both on account of the highly complicated nature of the fuel structure of the various classes of hydrocarbons present and also because of the greater number of engine variables which can be introduced.

It is, therefore, safe to prophesy that the rating of heavy oils for Diesel engines, as for petrol engines, must include suitable engine tests. It can be stated with a fair degree of certainty that heavy oils obtained from crudes which give motor spirits of the highest anti-knock value will be the worst from the point of view of combustion shock in a Diesel engine, and that those from crudes giving relatively low anti-knock value straight run spirits will be comparatively good.

All engine tests were carried out in the Research Laboratory of the Anglo-Persian Oil Co., and the Authors are much indebted to the Chemical Staff for their co-operation and assistance in the analysis and examination of fuel samples. The Authors also wish to record their thanks to the Directors for their permission to publish the results.

DISCUSSION.

The President said it would be appreciated that members had had the opportunity that evening of listening to a paper which, he felt, was going to be a landmark in the very difficult subject with which it dealt. The author had begun to do for the compression engine what Ricardo had done in the past for the petrol engine. In his own experience, serving on the B.E.S.A. Committee for Diesel engine fuels for the past ten years, from time to time there had been put forward criteria of the properties that such a fuel should possess: for example, the permissible limits of sulphur, the permissible limits of ash, of hard asphalt, of soft asphalt—every possible sort of test one could think of—and he thought that the authors had made a very strong point indeed when, in effect, they deprecated that multitudinous array of tests and fell back on the very obvious and natural test of the behaviour of the fuel in an engine. In the case of petrol, at the present time they had practically got down to fundamentals—the distillation curve interpreted the general requirement of volatility and the engine test demonstrated the resistance to detonation. A similar simplification would certainly come to pass in the present case. There was a certain tendency, a deplorable tendency, to multiply tests, and those who had anything to do with the testing side of the industry would put forward a very strong plea indeed to cut down those tests and to decide on which particular limiting conditions one could rely.

There was one interesting point in the paper that had appealed to him, and that was the reference to the spontaneous ignition temperature and the remarkably high figure of 520° C. for the S.I.T. of low temperature creosote. One would imagine that that was very definitely due to the hydroxylated bodies in the low temperature tar. It did not seem reasonable to imagine the hydrocarbon content producing so vast a difference as 250° C. over the average of the naphthenic and paraffinic base crudes.

He desired to mention one other point briefly—namely, the reference to dopes. He did not quite know why these three particular pro-knock substances were picked out, but it did appear that unless one could find a dope with about the same volumetric

efficiency as lead tetra-ethyl, then the utilisation of those low temperature oils as compression-ignition fuels did not appear to offer very much prospect.

Mr. J. Kewley said that he had come into rather close personal contact with one of the authors—Mr. Stansfield—in the work which the newly-formed Standardization Sub-Committee on knock-rating was carrying out, and he had the opportunity of knowing what good work they were doing.

He cordially agreed with the President as to the necessity of getting away from tests which might be meaningless or even misleading. When the Asiatic Petroleum Company started their work on the detonation of motor spirits he had foolishly hoped that by analysis of petrols in the laboratory into aromatic, naphthenic and paraffinic components, they would be able to predict the behaviour in an engine, but they had realised how impracticable that was.

The recent work of Edgar in the United States in synthesising isomeric paraffin hydrocarbons had shown that as big differences in engine performance were displayed by isomeric paraffins as by members of different series, so that laboratory determination of the classes of hydrocarbons present was insufficient and actual engine tests were necessary.

The peculiar behaviour of creosote was well-known. During the war, when attempts were made to utilise creosote in internal combustion engines, the difficulty of ignition made the use of a petroleum pilot jet necessary. This behaviour is a great difficulty in the way of finding home supplies of liquid fuel, by the distillation, at either low or high temperatures, of coal.

He had also had some experiences of dopes for Diesel oils, but had never found anything which was effective except in relatively large percentages which were prohibitive on the grounds of cost.

Dr. F. B. Thole said that the authors had put the engine testing of Diesel fuels on a footing with the knock-rating of petrols. Until quite recently the only methods of test available were analytical laboratory tests which gave a certain amount of valuable information especially as regards the presence of undesirable components both inherent and adventitious, but there had been no means of measuring accurately the behaviour of the fuel during combustion in the engine—after all, the most important of its qualities.

In the case of the petrol engine great advances had been made in recent times and the anti-knock value of a petrol could now be reported with a considerable degree of accuracy, thanks chiefly to the application of the " bouncing pin " device. The authors had applied the same principles to Diesel fuels, and it was due principally

to the use of the highly accurate and sensitive Farnboro indicator (which was in effect the equivalent of the bouncing pin) that they had been able to develop the beginnings of a method for the "anti-shock" rating of Diesel fuels.

It was interesting to note that whereas in the petrol engine paraffinoid fuels are less satisfactory in this respect than aromatic or naphthenic ones the reverse is the case among Diesel fuels. The creosote distillate from the "low temperature carbonisation process" quoted behaved very unsatisfactorily in the range of engines used and it seemed possible that products of greater or lesser anti-shock value than this sample might be obtained at other temperatures of carbonisation.

Mr. J. L. Chaloner said the paper was particularly interesting in so far as the facilities afforded by comparing performances of identical fuels on four different types of engine were bound to produce some useful evidence as to the behaviour of the various fuels under different combustion conditions.

Two or three of the speakers had rather stressed the desirability of an engine test. He ventured to suggest that, whilst that might have been a very good method of ascertaining the desired properties in the case of the petrol engine, they at the present time had not reached that ultimate stage of development of the compression ignition engine which would confidently allow them to decide on the type of engine.

If an engine test were established for comparing the performance of a certain fuel, he would be inclined to say that at this stage much time would be occupied in debating the right type of engine to use. To take a case in point there is still much controversy about the relative merits of the pre-combustion chamber type of engine and the plain combustion chamber construction. They, therefore, will have to rely to a certain extent on other factors, and the authors had given a very valuable lead as to how certain properties in the fuel might be used as a guide. In that connection he would like to know whether the large variety of fuels used in the engines were all commercial fuels. If such be the case there were very good prospects for the high-compression engine, because a multiplicity of fuels meant competitive fuels, and that meant cheap running.

There were one or two points that one could criticise in the paper, although one was rather diffident because one could readily understand the conditions under which the various results had been obtained. They were subject to the conditions of the laboratory. The facilities had been exceptionally good in the present instance, because, as he had said before, there were four different types of engine—well selected, high speed and low speed—so it was an

admirable basis for investigation. As regards the method of taking records, it would be interesting to know what had been the running-in period for each fuel before the final results used for tabulation of records had been taken. Also, what means had been adopted to make certain that the engine conditions had been stabilised on a comparable basis as regards the four different engines.

Again, he was not quite clear as to how the authors had introduced rather definite statements regarding the behaviour of the creosote when at the outset they definitely said that owing to the unsuitability of the fuel it could not be tested. If one could not test the fuel he did not see how one could draw conclusions with respect to some of the phenomena, such as delay times and delay angle.

There was one last point, and that was the leakage factor. The authors had said that in the case of kerosine, the leakage factor was a particularly heavy one. An engine designed to run on kerosine, should be run on kerosine; an engine designed to run on heavy fuel, would, if run on kerosine, show a higher leakage factor. It was not quite fair to introduce the leakage factor on an engine working on fuel for which the engine was not intended. He would have imagined that if another plunger had been fitted, the leakage factor could readily be reduced. That was just a practical suggestion which would, he thought, be permissible in the circumstances.

Mr. L. J. Le Mesurier, in reply, said that he thought there was general agreement that by carrying out tests in an engine a lot of meaningless tests would be avoided and the results obtained more definitely and more accurately.

It was quite true, as Mr. Kewley had said, that the use of creosote in engines had been adopted even before the War, by the use of a pilot jet and another fuel of sufficiently low spontaneous ignition temperature to ensure that ignition would take place. For that reason creosote was necessarily a difficult fuel to burn; but the possibility of somebody finding a dope which would do the job must be admitted.

Dr. Thole had discussed the importance of engine tests, and had made an interesting comparison between the Farnboro' indicator as a means of assessing the behaviour of fuels in an oil engine with the bouncing pin indicator used in the petrol engine.

Mr. Chaloner had mentioned that at the present moment engines had not reached a stage of development where it was possible to choose the correct engine for making engine tests; but one of the objects of the paper was to point out that the results obtained in a great variety of engines bore a very good relation to each other

and did not seem to be much affected by the type of engine used. He and his colleague thought that it would be quite possible to design a test engine which would give the results more readily than in the engines in question, but they considered that the general conclusions arrived at would not be modified appreciably by using a special test engine. He could confirm that all the fuels used in those engines were commercial fuels. It is possible to obtain commercially, not only these, but many other fuels lying within the same range.

The running-in period before taking the consumption test was about half an hour, until all conditions were quite steady, i.e., until the jacket, air inlet, lubricating oil, and engine, had settled down to a steady temperature.

With regard to the leakage tests, they had chosen kerosine as being a fuel of very low viscosity and as an extreme case to obtain a check point on an interesting curve. The use of fuels for which an engine was not really designed often gave extremely valuable information regarding more typical fuels. They had also chose a Robey engine as it was somewhat worn and corresponded to the condition of an average engine under normal running conditions. He quite agreed that it was not fair to expect an engine of the Robey type to run with a complete degree of satisfaction on a fuel such as kerosine.

With regard to the tar oil tests, while it was possible to obtain indicator records, mis-firing was too frequent for reliable consumptions to be taken.

Mr. Stansfield, in reply, said he would like to mention one point in connection with fuel behaviour. It is common experience that a great many complaints come from users about engine fuels, which are due to errors caused by neglect of suitable precautions, such as measurement of leakage, rather than to any difference between fuels. The difference in consumption between a fairly heavy Diesel fuel and a gas oil might amount to, say, 6 or 8 per cent. in an engine running under service conditions, and the user of that engine would charge up the poor consumption which he got on the gas oil against the gas oil and condemn it as a bad fuel as compared with a different fuel of higher viscosity. That was really the reason why they had made a particular point of conducting those leakage tests. They had found so often that fuels were condemned on account of behaviour which was not attributable to the fuel at all, but to the fact that the observations made had not been sufficiently complete.

On the motion of the President a vote of thanks to the authors was carried by acclamation.

The following was subsequently received from—

Dr. F. H. Garner :

Reference has previously been made to the fact that, as far as the testing of gasoline is concerned, we are now approaching the condition in which a standard method of determining anti-knock value is being laid down for universal use.

The situation as regards Diesel oil is shown in the present paper to be much more complex, and tests on the same fuel in the different types of engines do not place them in the same order.

Taking the delay angles as shown in Table No. 3, the fuels can be divided into two groups, Nos. 1 to 8 and 14 on the one hand, and 9 to 13 on the other, but the relative order amongst these two groups of fuels is not the same, even on the same engine under different conditions, and much less on the three engines. The relative order is different whether rate of pressure rise, delay angles or intensity of shock audibility are taken into account.

The measurements effect a separation into fairly well defined classes but do not approach the precision which can be reached in the knock-rating determination of gasolines.

There is one further point as regards the division of the test fuels into various classes of crude oil derivatives. Fuel 6 is described as from mixed base crude and fuel 8 from naphthene base crude.

These distillates are comparable as regards distillation range, but the carbon-hydrogen ratio indicates that fuel 8, derived from naphthene base crude is more paraffinic in character than No. 6 distillate, which was obtained from a mixed base crude, namely paraffin.

The Authors wrote in reply :

With reference to Dr. Garner's comment that tests on the same fuel on different types of engine do not place them in the same order, the same criticism may be made as regards gasoline testing engines.

Not only does the engine used for gasoline tests affect the rating in terms of the standard Octane/Heptane blends, but the working conditions also have a marked effect. It is, therefore, not to be wondered at that similar effects are noticeable with heavy oils, and one of our objects in using several different engines was to examine, as far as possible, the range of such differences.

If gasolines of widely different types were tested even on one engine, and at different speeds only, the ratings would vary appreciably.

It is, of course, admitted that the technique of fuel rating is not so well developed as that of spirit testing for anti-knock value,

but there does not seem to be any reason why the accuracy should not be much increased if a special engine were designed for the specific purpose of fuel testing. The important question to be answered, as in the case of spirit tests, is, what type of engine must be used to give the nearest approach to average working conditions. Probably the development of the high speed Diesel engine is not sufficiently advanced for an answer to be given at present.

As regards the classification of fuels Nos. 6 and 8, the former is from a crude giving a gasoline of low anti-knock value, and the latter from a crude giving a gasoline nearly 12 octane numbers higher in value.

Since the behaviour of the fuel oils agrees reasonably well with the classification according to gasoline type, it looks as though this is a better guide than the carbon/hydrogen ratio.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND THIRTY-FIFTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, April 14, 1931, the Chair being occupied by the President, Mr. JAMES KEWLEY.

THE SECRETARY read the names of members elected, as follows, and also the names of candidates nominated for election :—

As Members.—Albert Chadwick, Leonard Clement, Percy Erasmus Joyce, Brian Mead, Richard Stansfield.

As Transference to Member.—Wilfred Henry Thomas.

As Associate Member.—Archibald Fullerton Richmond.

As Transference to Associate Member.—Harry Cecil Rampton, Alexander Reid, Allan Ramsay Stark.

As Students.—William Edwin John Broom, George Cessford, Norman Colin Fraser, Philip Sinclair Verity.

THE PRESIDENT, in introducing Mr. Edmonds, said it was hardly necessary for him to do so, as he had been a member of the Institution for many years. He was a well-known authority on the subject with which the paper dealt. He had delivered a paper on a similar subject in 1928, and it would be interesting to find out what developments had taken place since that date.

The following paper was then read :—

Recent Developments in Fractional Distillation.

C. H. S. EDMONDS, M.Am. Soc. Mech. E., M. Am. Pet. Inst.(Member).

THE last few years have seen extensive development in the application of the now familiar system of flash distillation, and the many advantages of this method, visualised to some extent several years ago by advanced technicians, are being forcibly demonstrated in the operation of large-scale distilling units of the tube still and bubble tower type.

It may be of interest to observe how the single flash principle has spread. It was first applied to the simple topping process, to secure gasoline and has since been embodied in modern plant, capable of securing more than 95 per cent. of the crude as distillate products. It was found that a Pennsylvania-type paraffin base crude could be reduced to a specification cylinder stock, in a single continuous operation, at the same time securing as finished overhead

distillates, endpoint gasoline, naphtha, kerosine, gas oil and pressable wax distillate without any serious cracking as evidenced by higher flash points, and viscosities, and better colour.

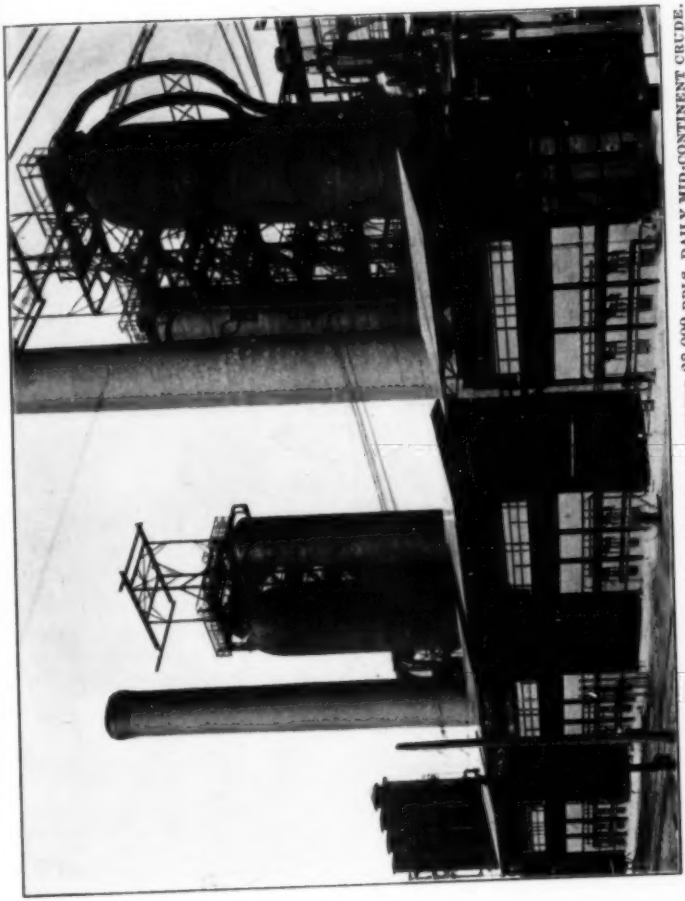
The ability to secure products to definite specifications and thus obviate redistillation has resulted in a greater yield of saleable product from a barrel of crude oil, and at the same time has increased the throughput of crude oil per unit of investment.

The use of modern tube stills and fractionating towers has permitted a reduction in operating costs of 50 to 60 per cent., as compared with the older type of shell still units.

The refiner has been faced with a definite and insistent demand for not only a better product, but also for a consistent grade of product, necessitating improved equipment and methods of manufacture. The advantages of distillation under vacuum have been recognised for many years, but the commercial application of vacuum to the processing of petroleum oils is relatively new, and the credit for success in this direction is perhaps as much due to the mechanical engineer as to the technician, and one of the most interesting developments has been the application of high vacuum to single flash distillation.

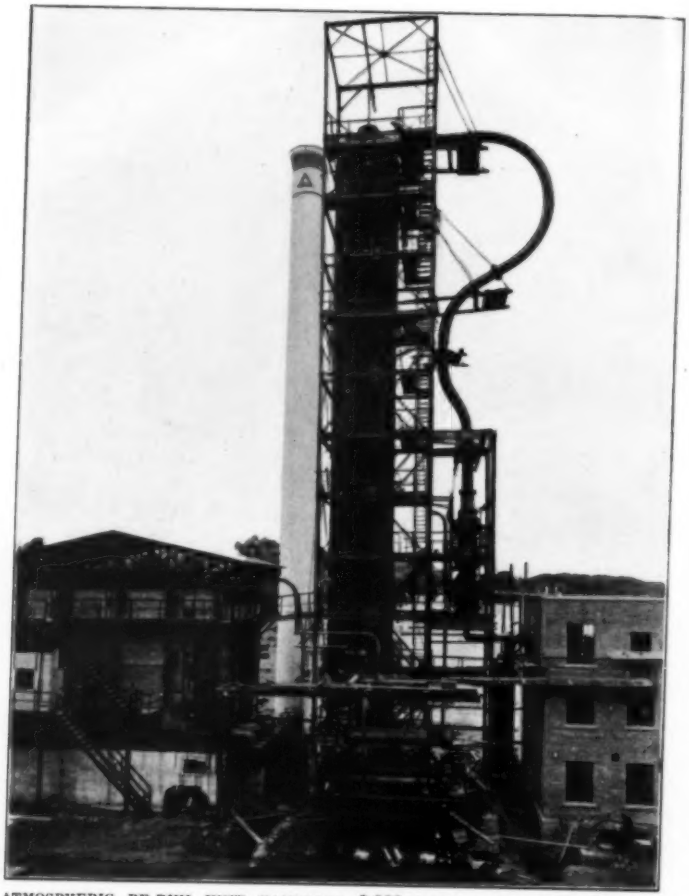
Crudes having either a paraffin base or having a definite asphalt content, such as the mixed base Mid-Continent type, may receive a more elaborate treatment. Such crudes are first processed by the single flash system under atmospheric pressure to yield such products as gasoline, naphtha, kerosine, light gas oil, together with reduced crude as a residue from this atmospheric operation. This reduced crude is then heated further in a tube still and flashed into a tower maintained under relatively high vacuum whereby heavy gas oil, pressable wax distillate and cylinder stock are taken off as distillate products, being effectively fractionated from the asphalt flux residue. By properly fractionating the wax distillate the colloidal wax and asphaltic materials are eliminated. Thus the maximum yield of pressable and sweatable wax distillate is obtained. The effect of the vacuum is to minimise decomposition and cracking of the oil, so that by this system it has been found commercially possible to process lower-grade crudes of high asphaltic content which heretofore had not been considered as a profitable source of lubricating oil. Modern practice has forcibly demonstrated the fact that by close and efficient fractionation it is possible to produce a cylinder stock with a negligible asphalt or tar content. In the case of wax free crudes the vacuum stage can be operated to yield four or five lubricating cuts of definite characteristics.

Turning from primary distillation of crude oil, we find a growing use of the single flash system in the secondary treatment or rerunning of cracked pressure distillate to obtain specification motor



TWO 2-STAGE ATMOSPHERIC AND VACUUM UNITS HANDLING 28,000 BBLS. DAILY MID-CONTINENT CRUDE.

UNIV. OF MICH.



ATMOSPHERIC RE-RUN UNIT HANDLING 8,000 BBLS. DAILY PRESSED WAX DISTILLATE.

spirit, in the subdivision of the dewaxed distillate oil into lubricating stocks of the required specifications and in the removal of solvent naphtha from centrifuged or cold settled bright stock.

These developments have resulted in the reduction of re-running, less loss of material due to more efficient processing, improved quality of products, and, in consequence, reduced distillation costs.

Designs have been developed possessing much greater flexibility not only in the products to be secured, but also in the crude oils that may be treated, and probably one of the most interesting applications of the flash distillation principle has been the development of small duo-purpose units for operation either at atmospheric pressure or under vacuum. Such equipment, which is of particular interest to the smaller refiner, may be used for topping and for running a reduced crude to asphalt bottoms.

It thus becomes important to analyse the details of the development of this newly-applied distilling system.

Developments in Tube Still Design—Primary Heating System.

This aims at heating the charge at a steady rate, bringing the charge homogeneously to the flashing temperature without overheating any portion, while yet operating the furnace at the highest useful temperature with the introduction of the minimum quantity of excess air. In a tube still designed for flash distillation purposes the charge is held only momentarily at the highest temperature before being discharged into the flash chamber.

The modern tube still contains two distinct banks of tubes, which are so arranged in the furnace that the oil enters those tubes which are set where they come into contact with the cooled combustion gases. These tubes are designed to transmit the heat, by convection and conduction, from the gas to the oil at high efficiency, resulting in a difference of less than 200° F. between the oil entering and the gas leaving the furnace. As the oil flows upwards counter current to the hot gases, the temperature gradient between gas and oil increases towards the top of this bank which is wholly separated from the combustion chamber by an air-cooled wall. It is important to ensure that the tubes in this convection bank should not be in contact with the high-temperature gases. The introduction of excess air would cool the gases, but to avoid such a waste of heat the principle of absorption by radiation is applied to the interior of the combustion chamber. Located across the length of the roof is a bank of tubes through which is circulated the oil from the convection bank, and these tubes absorb radiant heat from the combustion gases, floor and walls of the furnace,

at a rate which is many times the rate of absorption by convection and conduction.

Increased furnace efficiency has been obtained principally by the correct proportioning of the radiant and convection surfaces, which permits burning the fuel with a minimum quantity of excess air without increasing the furnace temperature, and also permits of very close control of the flash temperature. Sufficient radiant surface must be provided to prevent too high a transfer rate to the oil when the quantity of air supplied for combustion is barely sufficient to insure complete combustion of the fuel. This surface must be located at some distance from the burning fuel so that flame impingement is prevented and heat concentration is avoided. Even distribution of heat rays over the surface exposed to radiation is advisable to secure uniform heating. Furnace volume must also be considered, and from experience it has been found advisable to provide for a considerably lower rate of heat liberation than used in boiler practice. Furnace walls of considerable area are often constructed of the sectional type and air cooled. When the inlet oil temperature is sufficiently high, the flue gases are often still further cooled by preheating the air supplied to the furnace for combustion. The combination of these various factors results in increased fuel economy.

It is necessary to maintain turbulent flow of the oil through the tubes in order to avoid local overheating and to obtain a high coefficient of heat transfer. Turbulent flow implies relatively high frictional losses, which are further increased under conditions of high percentage vaporisation. In early types of tube stills the heating elements were connected by box type return headers which resulted in high pressure drop through these parts. By the use of stream line headers connecting the radiant heating elements, in which most of the vaporisation in the tube still takes place, the friction losses are considerably reduced.

When heating oil to about the critical temperature it is important to reduce the pressure so that a large percentage of the vaporisation may take place in the tubes, thus eliminating the necessity for heating the oil beyond the temperature required to produce the required vaporisation in the flash chamber. By the use of larger diameter tubes near the outlet of the tube still, the maximum amount of latent heat may be supplied before it is transferred to the flash chamber.

In modern practice the whole load of the pressure parts is carried by a steel framework quite independent of the furnace setting, thus eliminating undue strain on the brickwork walls.

Tube sizes vary from 2 in. to 6 in., and with high capacity these may be arranged for parallel flow to keep down the pressure drop.

Economy of steam has been secured by utilising the exhaust steam from the pumps as process steam after superheating it in a separate tube-bank set in the convection section of the furnace. In most cases, the necessary process steam may be secured entirely from the pump exhaust steam.

Developments in Fractionating Equipment.

The bubble tray fractionating tower is now almost universally used for the separation of the homogeneous vapour-liquid mixture into the specification distillate and residual products. In effect the tower unit embodies an evaporator or flash chamber section into which the mixture of oil in liquid and vapour form is flashed.

The liquid portion descends over a number of bubble trays, receiving counter currently from below the necessary quantity of superheated steam to strip it to a desired specification such as flash point, viscosity, penetration, etc., after which it is continuously withdrawn from the base of the tower by a hot oil pump.

The vaporised portion of the charge rises through a number of bubble trays upon which it contacts counter currently with a descending stream of liquid reflux, which is progressively vaporised by the ascending vapour, the heavier ends of which are condensed and at certain points in the tower taken out as liquid side streams.

A third component of the tower is the reboiling or stripping sections in which the liquid side stream products are brought to close specifications. These stripping sections permit the isolation of the nett yield of each side stream product from contact with the ascending vapour mixture and the reduction of it to conform to the required physical tests by open superheated steam, the liquid reflux being by-passed round the stripping section.

The uncondensed vapour leaves the top of the tower and its end point is controlled by regulating the vapour temperature by means of pumping back cold condensate on to the top tray.

Close control at this section of the fractionating tower is vital for efficient operation, and the amount of external reflux is generally automatically controlled by instruments provided for that purpose.

This system of top tower temperature control is now preferred to the use of partial condensers since it has been found more positive in application.

With certain designs of tower, it is possible by maintaining a constant top of tower temperature to maintain a constant temperature gradient throughout the tower regardless of variations in throughput. A particular type of weir control valve for side streams removes a predetermined proportion of the reflux quite independently of the total quantity flowing down the tower. Thus, the valve once set for a given set of operating conditions, it is

only necessary to pump back on to the top tray enough condensate to maintain a constant top of tower temperature, as the side streams will automatically, because of these control valves, accommodate themselves to varying quantities of vapour passing up and reflux flowing down. This arrangement serves greatly to steady the operation of the tower, and requires less supervision and changes in adjustment when the throughput varies. The only points of control are, then, the heater outlet temperature and the temperature at the top of the tower. The tube still outlet temperature is under the control of the stillman.

The same essential principles apply to towers working at atmospheric pressure and under vacuum, with certain modifications in construction in the second case.

In designing bubble trays for towers of large diameter and high rate of throughput, there is a danger of liquid becoming stagnant on parts of the tray so that good contact between vapour and liquid is not obtained. Of the two main types of bubble tray caps, the small circular type is being superseded by the long rectangular type, best results having been obtained with the latter variety combined with suitably placed liquid run-down pipes. This forces the liquid to a definite and evenly distributed path of travel across the plate and so ensures intimate contact in all parts.

Heat Recovery.

Although a large proportion of heat is expended in the bubble fractionating tower there is in the modern distilling unit recovery of heat almost to a point above which furnace efficiency would be impaired. That is, a preheat to 400° F. is not uncommon when the final temperature to which the charge is raised is 700 to 800° F. Latent heat is recovered from the overhead stream only, while from the tower side streams sensible heat only is recovered.

The use of heat exchangers results not only in a lower fuel consumption, but also considerably reduces the quantity of water required for condensing and cooling the products. Heat may be recovered from the overhead vapour, liquid side stream, and residue products, the location of heat exchangers being determined by the amount of heat available in the various streams, and the temperature at which they leave the bubble tower. By utilising as far as possible, the heavier products for preheating the charge, a high mean temperature difference is obtained with a consequent reduction of the heat transfer surface required per unit of heat input to the charge.

The shell and tube type heat exchanger with floating head is the type most used on modern pipe still plants. During the last

few years much has been learned of the principles and characteristics of heat transfer in these oil to oil, oil to water, oil to vapour and water to vapour heat exchangers. Again, as a result of plant practice and experiment, these units can be designed with much greater precision than formerly, and it has been shown that such heat exchangers will operate efficiently over wide variations of load.

It is well known that the heat transfer coefficient is a function of the thickness of the oil film on the tube surface and that this in turn depends on the viscosity and velocity of the oil handled. Here, as in tube stills, turbulent flow, with its resultant high friction loss, is essential for high transfer rates. For any given operation the only variable factors in a heat exchanger are the velocities of the two liquids, and these may be limited by pressure drop. The length of the tubes, the number of passes in the tubes and in the shell, and the baffling arrangement in the shell determine the pressure drop and hence the permissible velocity. The maximum length of the tubes is governed by their physical and mechanical properties, and by the number and arrangement of the tube passes. The temperature drop per pass and coefficient of expansion of the tube metal must be taken into consideration in order to prevent undue strain on the tubes and tube sheets.

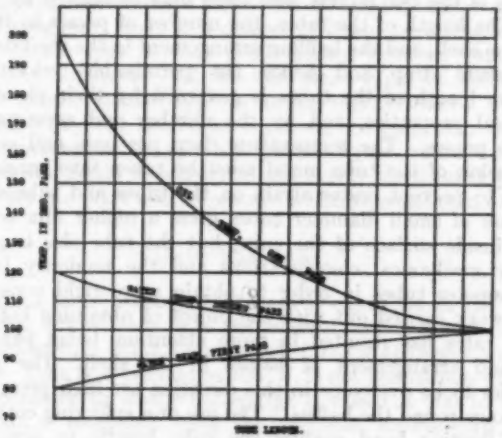
The use of small diameter tubes gives a higher film coefficient for the inside surface of the tube, but the tube size is governed more by mechanical considerations and the tendency is to use large diameter tubes in order to obtain more rigid construction. Recent work carried out with the object of obtaining higher heat transfer rates has resulted in more attention being paid to the shape and arrangement of baffles in the shell. The principal difficulties to be overcome in this direction are high pressure drop and leakage round the baffles. The use of a split ring construction for the floating head enables the tube bundle to almost completely fill the shell, thus ensuring intimate and even contact between the fluid and the outside tube surface.

The highest heat transfer rates are obtained, other things being equal, when water is used as the cooling medium, this being due to its low viscosity which enables high velocities to be employed without creating high pressure drops. The temperature to which water can be heated in a shell and tube type condenser or cooler depends principally on its hardness. High velocities are of assistance here, and it is worthy of notice that sea water may safely be heated to a temperature of 125° F. under suitable conditions.

The choice of materials is an important factor in design work, and depends principally on the operating temperatures and nature

of the fluids. For high temperature work mild steel and cast steel have proved very satisfactory, and corrosion is greatly minimised by even distribution of the fluid and the avoidance of stagnant sections. Corrosion must be most carefully guarded against in vapour condensers, particularly if steam is present, and under these conditions it is advisable to use cast iron shells and tubes of a non-ferrous metal such as bronze or Admiralty alloy. When salt water is used as a cooling medium non-ferrous metal tubes must be employed.

Leakage, which was a continual source of trouble in early heat exchangers, has been largely overcome by improved constructional methods, and particularly by expanding the tubes into double-grooved holes in the tube sheets.



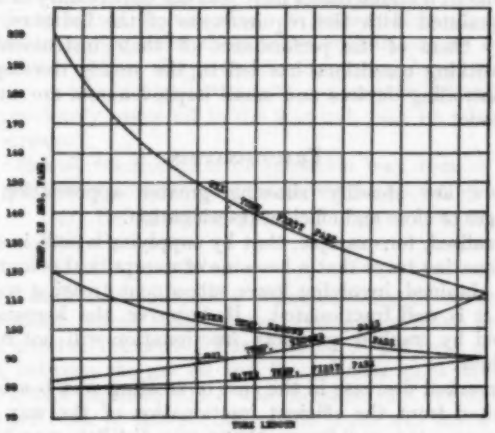
CURVE No. 1.

A recent development has been the introduction of a two pass in the shell and two pass in the tubes unit used principally for the final cooling of light products to temperatures within 1 or 2° F. of the cooling medium. These are of particular value in tropical or sub-tropical climates where the cooling water is warm, or for any operation involving low terminal temperature differences which are obtained as the result of almost perfect counter-current flow.

Curve No. 1 shows the maximum cooling which may be obtained in a heat exchanger with single pass flow in the shell and double pass in the tube bundle, an entering oil temperature of 200°, an

inlet water temperature of 80° and an exit water temperature of 120°. This is based on an infinite amount of cooling surface. With the limited amount of surface used in actual practice the exit oil temperature will be even higher than the 100° shown above.

Curve No. 2 is based on the same conditions as Curve No. 1 except that the shell is arranged for two passes of the liquid to be cooled. With the same entering and exit water temperatures a much greater degree of cooling is possible in theory, and obtained in practice when the new style exchanger is used. With the old style heat exchanger unavoidable leakage past the baffle materially reduces the theoretical amount of cooling obtained by the two pass design.



CURVE No. 2.

Owing to the high rates of heat transfer obtained in shell and tube units, and their resultant small size and weight, they can be mounted on a light steel structure and thus require very little ground space.

INSTRUMENT CONTROL OF TEMPERATURES, PRESSURES, ETC.

Much is being done towards adapting temperature and pressure measuring instruments for use on large scale distilling units. This is a very important section of distilling equipment, since the smooth working of a unit depends very largely on the performance of the instruments installed. Electrical recording pyrometers are

most suitable for the tube still temperatures. For the top tower temperatures, both electrical pyrometers and air, gas and mercury filled thermometers are in common use. These are commonly combined with a compressed air or electrically actuated valve controlling the amount of pump-back reflux, thus maintaining the desired temperature at the top of the tower. Orifice recording meters on the crude charging line are also combined with automatic air-operated control valves which regulate the steam pressure to the charging pump, maintaining the throughput at any predetermined rate. These instruments have to be made sensitive to sudden changes, constructed to withstand the severe conditions of working, and yet not be out of proportion in price compared with the rest of the equipment.

Instrument manufacturers have had the opportunity of becoming well acquainted with the requirements of the industry. Careful study by them of the performance of their instruments under actual working conditions has led to the steady development of these controlling devices and small improvements are continually being made.

Fractionation.

Refiners are steadily showing greater appreciation of the advantages of close and efficient fractionation.

It is realised, for example, that by supplying a sufficient number of fractionating trays that a kerosine of exceptional colour stability may be obtained, involving lower subsequent treating costs solely because it is well fractionated. If, however, the kerosine is contaminated by cracked products fractionation will not result in a good colour.

Very marked decrease in the cost of treating wax bearing crudes has resulted from the efficient fractionation of the wax distillate side streams. It is well known that a wax distillate may be successfully pressed if a porous crystalline wax structure can be built upon the leaves of the filter press. The presence of amorphous wax in a wax distillate destroys this crystalline structure by clogging the pores with a slime deposit. This reduces the capacity of the filter press and may even render pressing operation absolutely impossible.

Fortunately, the boiling point of amorphous wax is higher than the boiling point of crystalline wax, and it is quite possible to separate one type of wax from the other by efficient fractionation.

Most shell stills used in running crude oil to a wax distillate overhead are not fitted with fractionating equipment, and as a result the wax distillate produced in this way has a distillation curve showing a long tail between the 90 per cent. off point and the end point.

When running such stills to recover a maximum yield of overhead wax distillate, it is necessary to cut a slop wax, which must later be re-run for the production of pressable wax.

It is now known that pipe still units fitted with efficient fractionating towers make possible the recovery of the maximum yield of wax distillate to definite end point specifications, and eliminate re-running and the cracking of heavy wax distillate to render it pressable. Whereas formerly it was usual with shell still operation to take a pressable wax cut having 65-70 S.U. viscosity at 100° F. it is now possible to press an 85-90 S.U. viscosity at 100° F. wax distillate. The reason for this is as follows. With shell still operation the presence of amorphous wax in the pressable cut resulted in a deposit of slime on the cloth of the filter press which necessitated the retention in the cut of a large proportion of the gas oil in order to reduce the viscosity. With the efficient fractionation obtainable in a pipe still-bubble tower installation all amorphous wax is eliminated from the pressable cut, no clogging of the pores of filter cloths occurs, a higher viscosity cut may be pressed, and the gas oil, previously taken off in the wax cut, may be rejected to its natural stream.

Thus efficient fractionation of pressable wax reduces the subsequent processing necessary and minimises the operating load on :—

(*a*) Refrigerating plant.
(*b*) Presses.
(*c*) Re-run stills.

On old shell still equipment when running to recover a 150 viscosity steam refined stock, it was necessary to break up the wax distillate into two fractions. For example, 70 per cent. of the overhead cut between the gas oil and the cylinder stock bottoms was taken as a wax distillate which was pressable and sweatable. The other 30 per cent. of this portion of the crude was taken as a slop wax cut, which had to be re-run.

With modern pipe still equipment it is possible to make a good grade of pressable and sweatable wax from the unit when running to a residual cylinder stock having a flash as high as 585° F. without the removal of an intermediate cut of slop wax.

The quality of lubricating oil fractions has steadily improved as has also the yield of steam refined stock from pipe still as compared with shell still operation. This is demonstrated by the following table :—

Flash.	Saybolt Universal Viscosity.	Shell Still. %	Tube Still. %
550° F	150	15	20
585 „	205	12	16
600 „	225	10	14
630 „	—	7	11

The quantity of asphalt in the 150 vis. steam refined stock has been determined and found to be as low as 0·09 per cent. by weight.

Closely allied to the question of efficient fractionation is flexibility of performance. It has already been pointed out that efficient fractionation will in many cases given an improved colour and lower treating costs, and it is also true that flexibility of operation even with different kinds of crudes giving different products is largely a matter of supplying sufficient fractionating capacity.

In order to meet the demand for flexibility by refiners who are often called upon to process a variety of crudes and to produce a large number of special fractions for blending purposes, the height of fractionating towers has steadily increased. At the present time towers 130 to 140 feet in height are by no means uncommon. One such tower, the flow chart of which is shown in Fig. 1 gives nine products simultaneously, and is 155 feet in height.

Capacity of Units.

The capacity and size of distilling units have steadily increased owing to the fact that up to a limit dictated by constructional difficulties a single unit is cheaper both to build and to operate than a multiplicity of units of the same total capacity.

Fig. 2 shows the flow chart of a 14,000 barrel per day two stage unit situated in Texas, U.S.A. This unit handles Mid-Continent crude and produces :—

(*a*) Gasoline,
(*b*) Naphtha,
(*c*) Kerosine,
(*d*) Light gas oil,

from the atmospheric stage, and

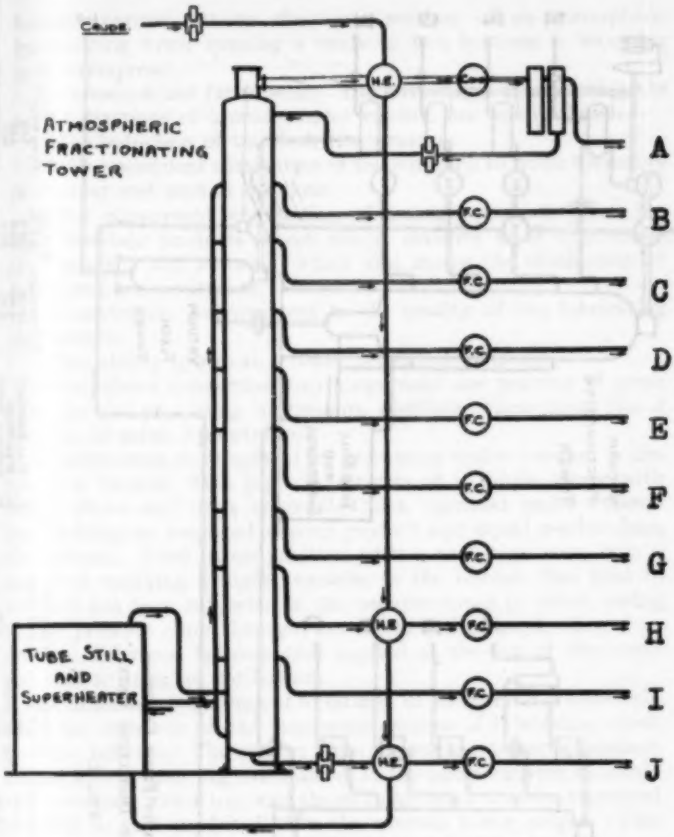
(*e*) Heavy gas oil,
(*f*) Wax distillate,
(*g*) Heavy wax distillate,
(*h*) Cylinder stock,
(*i*) Flux bottoms,

from the vacuum stage.

In accordance with increase in capacity the diameter of fractionating towers has gone up until 20 ft. diameter towers have been built and successfully operated.

Vacuum and Two-stage Operation.

The use of vacuum distilling equipment for the processing of reduced crudes to produce wax distillates, lubricating oils and specification asphalts is becoming daily more extensive. Not only so, but the use of a second vacuum stage to do the work



DIAGRAMMATIC FLOW CHART.—ATMOSPHERIC DISTILLING UNIT.

FIG. 1.

		Sp. Gr.	I.B.P. °F.	Flash °F. Closed Cup.
A.	Gasoline	0.715 ..	90 ..	—
B.	200-300 Naphtha ..	0.759 ..	223 ..	—
C.	300-400 Naphtha ..	0.774 ..	278 ..	79
D.	Kerosine	0.793 ..	340 ..	119
				Open Cup.
E	Furnace Oil	0.808 ..	— ..	180
F.	300 Oil	0.821 ..	408 ..	215
G.	Gas Oil	0.841 ..	366 ..	275
H.	Wax Distillate ..	0.857 ..	— ..	315
I.	Closed	— ..	— ..	—
J.	Cylinder Stock ..	0.903 ..	— ..	561

DIAGRAMMATIC FLOW CHART.—TWO-STAGE DISTILLING UNIT.

FIG. 2.

		Percentage.	Gravity °A.P.I.	Flash °F. Closed Cup.
A.	Gasoline	31.30	58.7	—
B.	Naphtha		No cut taken.	
C.	Kerosine	13.88	42.3	173
D.	Gas Oil	4.81	36.2	173

		Percentage.	Gravity °A.P.I.	Flash °F. Open Cup.
E.	Wax Distillate	25.06	29.9	325
F.	Wax Naphtha	4.64	33.9	470
G.	Cylinder Stock	6.42	29.5	435
H.	Flux Bottoms	6.42	10.5	Penetration 160.

formerly carried out by the lower sections of an atmospheric fractionating tower running a crude to flux bottoms is becoming more widespread.

The reason is not far to seek. The advantages of processing the heavier fractions of a crude under vacuum are briefly these :—

1. The reduction of the flash temperature.

2. The consequent elimination of the tendency to crack the heavy lubricating and asphalt fractions.

3. The consequent elimination of cracked products from the light distillate products whose colour stability is of importance (e.g., gasoline and kerosine) which also means the elimination of gum forming constituents.

4. Considerable improvement in the quality of the lubricating oil fractions.

5. The ability to run to a lower percentage bottoms.

In the above connection two stage units are proving of great value in the processing of pressure distillate where item No. 3 above is of prime importance.

An interesting development in processing under vacuum is the use of a vacuum flash jug. It consists of a simple tower with baffles above and trays below the inlet, operated under vacuum and yielding an overhead vapour product and liquid residue from the bottom. Used in conjunction with a two-stage unit, it is a means of applying a higher vacuum to the residue than that to which it has been subjected in the vacuum tower in which, owing to the pressure drop through the fractionating trays, there is a pressure difference between that applied at the top of the tower and that existing at the bottom.

This difference may amount to 60 mm. of mercury and adversely affect the recovery of the maximum amount of lubricating stock from the bottoms. The residue from the vacuum tower is therefore flashed into a flash jug maintained at the same vacuum as exists at the vacuum tower top, and the cylinder stock thereby vaporised is added to that produced from the vacuum tower proper. This type of operation is illustrated in Fig. 2.

The vacuum flash jug may also be used with advantage as an adjunct to a single stage atmospheric tower when it is desired to run to a low percentage bottoms.

In so far as the vacuum flash jug has been developed primarily for use on residue products, as a means of circumventing the drop in vacuum from top to bottom of vacuum fractionating towers, and as full advantage is taken of the carrying effect of the steam used, it retains the advantages of the single flash system.

Such, however, is not the case where refiners have been tempted to subject the crude oil to be distilled to a preliminary flash after

passing through the heat exchangers and before entering the tube still. In this case the carrying effect of the light ends upon the heaviest is lost, because at the temperatures attained by the crude oil in the exchangers the vapour pressure of the heaviest ends is comparatively small and flashing at this low temperature does not help materially in their vaporisation. Consequently, in the tube still proper, a higher flash temperature, or additional steam, is required, than if a closed system up to the fractionating tower were used.

Conclusion.

To sum up, recent years have witnessed the widespread adoption of vacuum distillation as a means to meet the demand for stable overhead distillate products with the evolution of two-stage atmospheric and vacuum units for the complete and satisfactory separation of a crude oil into as many commercial fractions as it is capable of yielding. They have seen vacuum units supplanting almost completely atmospheric plant for the fractionation of lubricating oils and waxes, and the securing of the maximum yields of these products from reduced crudes.

There has been an all round increase in the efficiency of distilling equipment, in fractionating capacity per unit of tower volume, in heat transfer capacity per unit of tube still and heat exchanger surface, all accompanied by better quality products, and increased efficiency in the recovery of the most valuable constituents of the oil under treatment.

In these days of strenuous scientific advance this is a record of which the petroleum industry may well be proud and should the next few years show the same progress as has been made in recent years we can be sure that in the sphere of distillation it is at least keeping abreast of the times in the application to industry of modern scientific knowledge.

APPENDIX.

The following operating results may be of general interest:—

Table No. 1 presents data obtained on an atmospheric unit when running Seminole crude to flux bottoms.

TABLE I.

Performance Data on an Atmospheric Unit.

Thruput—Seminole crude	6300 B/D
Gravity	39·7° A.P.I.
Temp. tube still inlet	350° F.
Temp. tube still outlet	800° F.
Temp. superheated steam	750° F.

	Yield. %	Gravity. °A.P.I.	Colour.	E. P. °F.
Gasoline	39·5	60·0	22	442
Kerosine	4·4	41·4	17	—
Gas Oil	25·1	36·0	—	—
Wax Distillate	10·3	29·6	—	—
Cylinder stock	8·7	—	Vis at 210° F. 98	—
Bottoms	9·8	12·0	—	—
Loss	2·2	—	—	—

The addition of a vacuum flash chamber increased the yield of cylinder stock from 8·7 per cent. to 13·4 per cent., the cylinder stock from the vacuum chamber having a viscosity of 138 secs. at 210° F. The bottoms were reduced to 6·5 per cent. The conclusion drawn from the data presented may well be that to always insure good colour of the lighter products, as well as an increased yield of overhead cylinder stock of higher flash, a vacuum flash chamber should be installed as an auxiliary to the main tower.

Samples of streams recovered from atmospheric distillation of Seminole crude when running to 15·9 per cent. bottoms with a tube-still temperature of 750° F. showed that at this temperature the colour of the gasoline was 30+, and the kerosine 24. At higher temperatures the colour of these streams gradually fell off, and at 800° F. tube-still temperature the gasoline was 22 colour and the kerosine 17 to 18 colour.

A four-day run on Seminole Mid-Continent Crude through a two-stage atmospheric and vacuum unit, using an auxiliary vacuum tower to flash the bottoms from the main vacuum tower, is tabulated in Table 2.

TABLE 2.

PERFORMANCE DATA ON TWO-STAGE ATMOSPHERIC AND VACUUM UNITS WITH AUXILIARY FLASH TOWER.

Temperature °F.	
Oil entering atmospheric tube still	361° F.
Oil leaving atmospheric tube still	599° F.
Oil entering atmospheric tower	572° F.
Vapours top of atmospheric tower	303° F.
Oil entering vacuum tube still	528° F.
Oil leaving vacuum tube still	774° F.
Oil entering vacuum tower	750° F.
Vapours top of vacuum tower	407° F.
Oil entering flash tower	687° F.
Vapours leaving top flash tower	678° F.
Bottoms leaving flash tower	676° F.
Thruput (2 units)	27,130 B/D.
Fuel used (by volume)	2·36%
Steam Used (2 units).	
Total live steam (pumps and jets)	17,664 lb./hr.
Total exhaust steam used	17,166 lb./hr.
Water used	5,980 G.P.M.

Yields.	B/D.	%
Total Crude	27,130	100·00
Gasoline	7,724	28·47
Kerosine	4,024	14·83
Gas Oil	2,844	10·48
Wax Distillate	7,263	26·77
Heavy Wax Distillate	1,403	5·17

Yields.	B./D.	%
Cylinder Stock	1,862	6·86-150 vis. at 210° F. 535° F. Flash.
Flux	1,870	6·89-10·1°A.P.I. 108° F. M.P.
Loss	140	0·53

The yields for a corresponding run with Seminole crude without the flash tower are tabulated in Table 3.

TABLE 3.

YIELDS FROM TWO-STAGE ATMOSPHERIC AND VACUUM UNIT WITHOUT AUXILIARY VACUUM FLASH TOWER.

Yields.	B./D.	%
Total Crude	13,518	100·00
Gasoline	3,865	28·6
Kerosine	1,620	12·0
Gas Oil	1,810	13·4
Wax Distillate	3,705	27·4
Wax Slop	568	4·2
Cylinder Stock	758	5·6–151 vis. at 210°F. 525° F. flash.
Flux	935	6·9-11·1° Be. M.P. 94° F.
Loss	257	1·9

It is evident from Tables 2 and 3 that to obtain the best colour of light products and the maximum yield of cylinder stock a two-stage atmospheric and vacuum unit, supplemented by a vacuum flash tower as an auxiliary to the main vacuum tower, is required. However, the increased yield of cylinder stock is so small that the advisability of the increased investment would depend largely on specific conditions.

Table 4 lists the performance when running various crudes in a two-stage atmospheric and vacuum still but without the auxiliary flash tower.

TABLE 4.

PERFORMANCE DATA ON A TWO-STAGE ATMOSPHERIC AND VACUUM UNIT WHEN POSSESSING VARIOUS CRUDES.

Test No.	1.	2.	3.
Kind of Crude.	Venezuela.	Caddo.	Oklahoma City.
Gravity of Crude, °A.P.I.	17·7	23·7	38·2
Duration of test, hrs.	120	16	120
Thruput, B.P.D.	11870	9480	8520
Fuel used, % thruput	1·64	—	2·31
Temperature °F.			
Oil entering atmospheric tube still ..	330	380	340
Oil leaving atmospheric tube still ..	615	590	580
Vapours top atmospheric tower ..	252	285	225
Steam entering atmospheric tower ..	780	725	700
Oil entering vacuum tube still ..	570	525	510
Oil leaving vacuum tube still ..	650	810	820
Vapours top vacuum tower	—	325	325
Steam entering vacuum tower ..	575	725	675

Steam Used, Lb./Hr.			
Total live steam	9300	—	8830
Exhaust steam atmospheric tower/G. crude	0·06	—	—
Exhaust steam vacuum tower per gal. reduced crude	0·14	—	—
Water Used, G.P.M.	2540	—	2540
Yields, per cent.			
Naphtha	6·91	1·46	30·14
Refined oil	8·81	5·13	20·75
Gas oil	16·39	29·26	5·16
Light lube "A"	13·98	—	—
Heavy lube "B"	3·66	—	—
Motor oil	—	42·14	—
Paraffin distillate	—	—	24·80
Cylinder stock	—	4·07	9·32
Heavy flux	49·13	18·35	9·08
Gas and loss	1·12	+·41	0·75

Successful runs were also made on Lago crude running to

50-60 Pen. Btms.
80-100 „ „
100-120 „ „
900-1200 Vis. Btms.
470-490 Flash Btms.

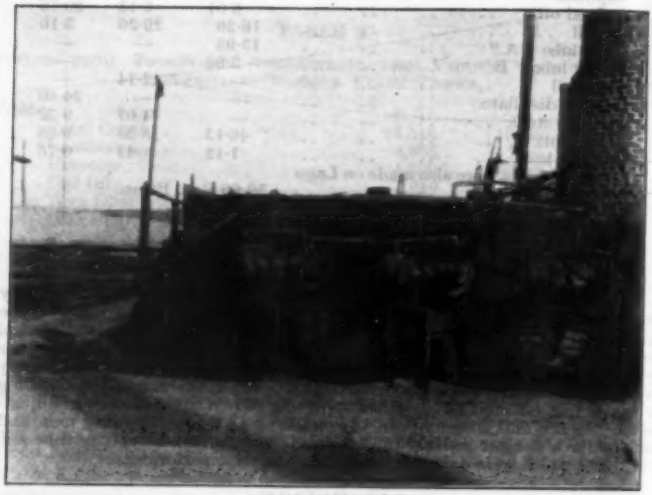
The range of operation shown by Table 4 indicates the flexibility which may be secured from the modern type of tube still fractionating tower. The design and arrangement of bubble trays and stripping sections, and control valves used are largely responsible for close control of fractionation. It is evident from data submitted that a unit of this type can function economically over a wide range of operations from light topping at one extreme, to running to heavy flux bottoms at the other, requiring only a slight change in adjustment. Such a unit therefore can be considered as a general utility unit, and thus marks a distinct increase in usefulness over the earlier types of tube still and tower which were definitely limited to a specific performance.

DISCUSSION.

The President said it would be agreed from what Mr. Edmonds had said that there has been a considerable advance in the art of fractional distillation during the last three years. The fractionation as shown by some of the curves was certainly very good. He pointed out that the single flash principle was in use in California in 1912 for the topping process and also for dehydrating crude oil. When distilling a crude which contained water it was often advantageous to use a small dehydrating unit, consisting of a pipe still and evaporator before the main tubular furnace. If a crude oil containing saline water be evaporated in a pipe still trouble owing to deposition of scale will ensue, but if the water has been evaporated off, the presence of the dry saline matter will not cause any trouble of that kind.

There was certainly a great increase in the use of vacuum distillation. There was one application of the distillation process to which Mr. Edmonds had not referred. This was the stabilization

of natural gasoline. Large quantities of natural gasoline were nowadays obtained by the absorption process with such high vapour pressures, so that they were not usable without being first stabilized. This was a process of distillation not under vacuum but under pressure. There were many such units now in existence, similar in principle to those which the author had described, with which it was possible to fractionate very closely



ORIGINAL TRUMBLE PLANT AT FELLOWES, CALIFORNIA, 1912, SHOWING PRIMITIVE TUBULAR STILL.

and to isolate, for example, a butane boiling within about 5° F. and to cut out if desired an isobutane fraction. The efficient fractionation of natural gasoline was becoming increasingly important because of the new specifications which were being introduced defining the various types of natural gasoline on the market.

He had been very much interested in the results obtained in the distillation of wax. In the old days one of the difficulties of obtaining a pressable wax was that the heavy distillates which came over with the wax were so viscous that the wax could not be well separated, and a certain amount of cracking distillation was necessary in order to get a thin distillate. It appeared, however, that with improved fractionation a narrower cut could be obtained which gave a higher yield of good pressable wax.

The author had mentioned stills with pipes in parallel and he desired to ask Mr. Edmonds whether there was not any danger from uneven distribution of the current, resulting in coke deposition, the effect of which under such conditions would be rapidly cumulative.

Mr. G. H. Coxon said that the first thing that had struck him was the colossal size of some of the vacuum units described. A few years back vacuum units were of 200 or 300 barrels capacity, but now they were built with a capacity of 30,000 barrels. It was only the large companies that could afford such big units. That showed what the small producing companies were going to be up against. They had got to put in small units, whereas if the big companies put in very big ones, bringing their costs down at one fell swoop, they were going to set the pace on the prices. He believed that that was one of the difficulties they were meeting at the present time in the petroleum world—that in the last five years the big companies in the United States had so cut their operating costs, and above all, increased the yield of saleable products, that entirely apart from the flooding of the crude oil production they were flooding the markets with their products. He remembered a refinery which used to get about 10 per cent. of lubricating oil that now, with two or three men per shift operating it, was getting three times as much. He thought the industry must be prepared for lower prices due entirely to the modernization of units.

The author had interested him very much in the vacuum pot. It was the first time he had seen that fully described. If that was going to add another 5 or 6 per cent. of distillate it was either going to reduce the temperature question or add to the capacity of the unit. He believed that one of the greatest advantages of the modern vacuum pipe stills was in a saving of viscosity or an increase in lubricating heavy stock for motor cars, instead of the light spindle oils which nobody could sell to-day. If that increase has been accomplished by the addition of the vacuum pot without additional cracking in the pipe still it was a very big step forward.

He could speak with a little experience on the operating costs of some of the fairly large units. He knew of one company that had cut its cost down from about 2s. to about 8d. per ton input. That was quite a big reduction on a unit turning out several thousand gallons a day. If anyone cared to multiply that by the thousands of barrels that some of the larger refineries turned out, it showed what costs were coming down to. The companies with the modern equipments would undoubtedly set the pace, and he would like the author to tell the meeting how the operating costs of the small units were going to compare with the operating costs

of the large units. How would a small European company compare with the large companies in the United States which went in for 30,000 barrel units? Had the smaller companies any chance of living, except by competitive tariffs?

Mr. A. A. Ashworth said that one of the most interesting sentences in the paper to him personally was the following: "When heating oil to about the critical temperature it is important to reduce the pressure so that a larger percentage of vaporization may take place in the tubes, thus eliminating the necessity for heating the oil beyond the temperature required to produce the required vaporization in the flash chamber." This was a partial step in the right direction, but why was it necessary to have any vaporization in the flash chamber? Why not complete it in the still and save having to superheat the oil in order to provide the latent heat for the vaporization in the flash chamber? A greater percentage of distillation could always be obtained at an equal temperature or, conversely, the same percentage at a lower temperature by so constructing the pipe still that vaporization could be completed in the still itself so as to take full advantage of the partial pressure effect of the mixed vapour. To do this it would be necessary to do more than merely enlarge the diameter of the pipes. It would be necessary to construct a vaporization section consisting of a comparatively large number of pipes in parallel and to connect this section by a large diameter transfer line to a separating chamber, which would no longer be a vaporizing chamber. The velocity in this transfer line would probably range from 50 to 100 ft. per second, and be no greater at the end of the parallel pipes forming the evaporating section.

If one looked at the temperatures given in the author's Table II., it would be seen that there was a drop in temperature between the oil leaving the still and entering the towers of 24 to 27°, showing that vaporization was not complete. Further, if the temperature had been observed at the end of the heating surface, he ventured to assert that the temperature difference would be much greater. A considerable amount of vaporization must take place in the transfer line.

The author had referred to the problem of obtaining the maximum yield of distillates from oils of mixed base and asphaltic base origin. In the stills which he had described a vacuum pipe still was combined with a separating chamber and fractionating column. The fractionating column would prevent really low distillation pressures being maintained at the heating surfaces, and either yield must be sacrificed or temperature be maintained unduly high for maximum yield. In most cases it was commercially desirable to get the maximum percentage of distillate

within a limited temperature range, and to achieve this it might prove profitable to make a primary distillation with the highest vacuum commercially obtainable. From this a broad lubricating distillate would be obtained which could be chemically treated in bulk and afterwards fractionated in a pipe still fitted with the necessary fractionating chamber, where easier conditions would prevail owing to there being no necessity to redistil the cylinder oil cut which would form the residue from the redistillation. With such a scheme, where very high vacuum was maintained the pipe still would consist almost entirely of an evaporating section of parallel pipes with a small preheating serpentine. The cost of the extraprimary distillation would be offset by the increase in yield and reduction in treating cost and losses owing to the better initial colour of the distillate.

He could not think that the vacuum flash jug described by the author would prove very successful in materially increasing the yield of distillate. In the evaporating chamber evaporation had been carried out at a moderate vacuum with a certain but not full benefit of the partial pressure effect of the mixed vapours. In the vacuum flash jug it was attempted to carry distillation farther by increasing the vacuum but removing the partial pressure effect. That was like first using moderate vacuum with steam and then high vacuum without steam.

Dr. F. H. Garner said that perhaps the most interesting part of the paper was that which dealt with fractionation under vacuum, in which the most marked progress had recently been made. Reference had been made to the advantages of flash distillation in that the light vapours helped to carry over the heavy vapours present and thus enable lower distillation temperatures to be used. The vacuum tower or vacuum jug, according to the figures in Table II. or III., allowed an extra yield of 1·25 per cent. of cylinder stock to be obtained with about 7 per cent. flux residue from the Seminole crude. In this tower the help of light vapours in flash distillation, such as is present in the atmospheric or vacuum tower, is not available, but the device is very interesting as a method of rendering the full vacuum available for the bottoms leaving the vacuum flash tower. It would be of interest to have analytical data for the distillate taken off in the auxiliary tower, as compared with those taken off in the vacuum unit, if such figures are available.

Mr. E. Lawson Lomax said it was admitted nowadays by everybody in the petroleum industry that the methods of distillation described by the author were far ahead of the old methods of the ordinary cylindrical still distillation. One of the reasons

for this was that there was a relatively small amount of oil in process compared with the throughput of the plant. The dangers from fire in that case were much less. The oil was heated for a very short period. He did not know what the author calculated was the time of heating of his oil, but it must be a very short time, whereas in the old type of continuous distillation bench the oil was heated from the time it entered the distillation bench to the time it left, and this time must have been several hours. After a certain point it did not matter what one did: if a certain temperature was reached cracking was bound to take place to a greater or less degree according to the temperature and the time of heating. Therefore the types of distillation units described by the author must reduce the cracking of the stock which was being treated. For those reasons he thought undoubtedly they were the distillation units of the present and of the future.

There were one or two little points in the paper that he desired to mention. On the first page of the paper the author referred to the fact that "the advantages of distillation under vacuum have been recognised for many years, but the commercial application of vacuum to the processing of petroleum is relatively new." He did not know what the author meant by "relatively new," because the petroleum industry itself was relatively young compared with other industries, and he had seen vacuum distillation units which at the time when he saw them had been working for well over thirty years, and it was some years since he had seen them; so the distillation under vacuum of petroleum products must have been practised on a commercial scale for over forty years, probably fifty years; and he thought possibly right from the beginning of the petroleum industry a certain amount of vacuum distillation was employed in some cases.

Another point which had struck him during the reading of the paper was that the author mentioned the flexibility of the units he had described—i.e., their capability of distilling either asphaltic stock crudes or paraffin base crudes. He did not think, however, that that was peculiar to the pipe unit; any unit would distil them; that did not matter. Up to a certain point, the distillation was the same whether they were of asphaltic or paraffinic base; the only difference was that, if one got the very good fractionation which was provided for in the very efficient columns described, then in distilling a wax bearing stock one got the fractionation which cut out the amorphous portion of the distillate. That, of course, could be accomplished with the ordinary type of vacuum distillation plant, i.e., the older type, providing the columns were sufficiently efficient.

Dr. F. B. Thole asked the author whether he would be able to indicate more precisely in his paper what pressure he implied when the term " vacuum " was used ?

The term " Vacuum " in petroleum technology was often used when " reduced pressure " might be a more appropriate term, for some lubricating oil stills worked at a pressure of 10-15 mm. of mercury and others at 100-150 mm., and it would enhance the value of some of the experimental data quoted if the absolute pressure on the oil surface could be stated.

Mr. C. R. Scott Harley asked the author whether he could say a little more about the pressable and the non-pressable distillate ? He was very much interested in the wax fraction and as to what it was that was recognised as producing a pressable material without actually pressing it. What had happened to the non-pressable portion ? In one of the diagrams which the author had given he had put in a side stream with a note that it was " not used " except for balancing the wax distillate with the heavy lube fraction and making the latter up to specification. In this case, are we to assume that the non-pressable portion is normally concentrated in the lube side stream or carried as far as the residuum ? Would the author inform the meeting where the non-pressable section had gone to and what are the boiling-point characteristics of the pressable and non-pressable part which make it possible to separate them into definite cuts in a fractionating tower ?

Mr. Edmonds (in reply) said that Dr. Thole had brought up a point regarding the use of the term " vacuum." He quite agreed with Dr. Thole that one used the word " vacuum " very loosely at times. They were trying once more to get into the habit of using the words " absolute pressure " ; but throughout the units he had described, generally speaking, the absolute pressure at the point of flash in the fractionating tower was about 80–100 mm. of mercury, which meant that at the barometric condenser there would be an absolute pressure of 20 mm.

It was very good of Mr. Coxon to refer to what was, after all, one of the most important points in the development of distillation, namely, the commercial side, because unless the designs justified themselves by reduced costs then there was no more money left to develop the industry and get better designs.

With reference to relative operating costs, he would be almost inclined to suggest that a 30,000-barrel unit could be operated at a total cost not exceeding the 400-ton unit. In the first place, when a large oil company decided to put in a 30,000-barrel unit the cost was not confined to the distilling unit, but included numerous

additional equipment. It required in itself a large pumping system, a large tanking system, all of which had to be thought out, and the money provided. On the other hand, one frequently found that the refiner with 400 tons to handle spent most of his money in buying the distilling unit, and then had to make do with his existing equipment, which frequently entailed a greater amount of labour to operate than was found on the big unit. He would say that to-day one could operate a unit of ten times the capacity for the same labour.

In answer to Mr. Ashworth's and Dr. Garner's question with reference to the flash jug operation it was of course true that the carrying effect of the lighter fractions already removed in the atmospheric and vacuum towers was lost. On the other hand a two-stage unit used in conjunction with a flash jug was in reality a three-stage unit. The criticism Mr. Ashworth had directed towards the operation of a flash jug after the main vacuum tower could be applied with equal validity to the use of a vacuum stage after an atmospheric.

It would therefore appear that the use of a flash jug was merely a natural extension of the two-stage atmospheric and vacuum distillation which had been so widely adopted, and the use of a second stage operated at reduced pressure after the atmospheric stage was sufficient justification for the use of a flash jug at a still further reduced pressure after the first vacuum stage.

The vacuum stage and flash jug conditions were similar in that steam was employed in both, and the only difference was in the effective vacuum which could be obtained.

He regretted that he had no comparative distillations of the distillates secured from a two-stage unit operating with and without the flash jug.

He thanked all members for the very kindly way they had received him, and in particular he desired to express his appreciation of the assistance rendered to him in the preparation of the paper by Mr. Harper.

The President then proposed a vote of thanks to the author for his paper, which was carried with acclamation.

The Corrosive Effect of Gasolines and Motor Benzoles on Copper.*

By F. H. Garner, Ph.D., M.Sc., F.I.C. (Member) and E. B. Evans, M.Sc., A.I.C. (Assoc. Member).

In recent years a considerable amount of attention has been directed to the corrosive action which certain motor fuels exert upon the metal parts of the fuel systems of automobile and aircraft engines.

The corrosion is due to the formation of a black deposit which has been shown [4, 6] to be mainly a mixture of copper sulphides, on the carburettor floats, jets and gauzes and on the fuel pipes. Gauzes have been completely blocked, floats badly corroded, and jets choked owing to the deposition of sulphide. It is obvious that the alteration of fuel flow which may follow from this corrosion may give rise to wastage of fuel or loss of power.

It has been shown that free sulphur is an active corroding agent to copper, and also that certain sulphur compounds with loosely attached sulphur will also cause this formation of sulphide.

The problem of detecting and identifying the corrosive factors with a view to their elimination and of devising satisfactory tests for the detection of corrosive action and the estimation of the amount of deleterious matter present, is obviously of interest both to the refiner and the marketer of motor fuels. A clause is included in some specifications in order to insure the absence of " corrosive " sulphur.

A summary of the previously published literature on this subject is given below, and this is followed by an account of experimental work carried out with the objects of selecting the most satisfactory test for corrosion and devising a convenient and accurate method for the estimation of " free sulphur," together with some discussion of the results.

One of the earliest attempts to detect and estimate the corrosive sulphur in petroleum products was made by Sanders in 1912[1]. As a qualitative test he proposed the observation of the discoloration of pure copper foils cleaned with 10 per cent. potassium cyanide, immersed in the product to be tested. The potassium cyanide was said to sensitize the copper. Sanders proposes also two quantitative methods for estimating the corrosive material; one

* Paper received January 31, 1931.

of these involves distillation over metallic sodium and oxidation to sulphate, which is estimated gravimetrically. Another and quicker method consists in refluxing the sample with cleaned copper turnings, dissolving the copper sulphides in potassium cyanide, oxidising, and finally estimating the sulphur as a sulphate.

The next published work on this subject is that of Lomax[2]. After mentioning the corrosive effect on carburettors, he describes a test which he originated in 1909. The sample is distilled from an Engler flask containing a 2 x 1 cm. piece of copper foil, cleaned with potassium cyanide. Note is taken of the amount of stain produced and the point of the distillation at which the discoloration first appears. By calibrating against spirits of known sulphur contents, it is claimed that a good and quick estimation of the sulphur content of the sample may be made. No distinction is apparently made in this paper between "total" and "corrosive" sulphur. Sanders, on the other hand, describes his test as applying to "loosely combined" sulphur.

Reference is made by Waters[3] to the effect of free sulphur and hydrogen sulphide on copper. A few drops of the oil are left on a piece of polished copper for, say, twenty hours at room temperature, and the appearance of the copper is noted. With regard to the estimation of total sulphur in oils, some experiments were carried out by heating the sample with copper powder or copper oxide and dissolving the residue in dilute hydrochloric acid containing bromine. Considerable amounts of sulphur were removed by this method, but the results were not reproducible.

Ormandy and Craven[4] proved the presence of elementary sulphur in some corrosive spirits and considered that this was mainly responsible for the trouble experienced. They adapted and correlated Lomax's method with contents of elementary sulphur, and found quite good agreement. They suggest that any spirit containing not more than 1 mg. per 100 ml. may be considered as commercially free. They tried also several methods of estimating the free sulphur with the object of devising a volumetric method, but finally decided on the method of shaking with mercury, which has since been modified and standardised in 1929 by the Institution of Petroleum Technologists[2a].

In a paper on "Sweetening" in the petroleum industry, Wendt and Diggs[5] consider the estimation of various sulphur compounds and free sulphur. They estimate the latter by adding a solution of ethyl mercaptan and plumbite solution to the gasoline, shaking, dissolving the lead mercaptides in dilute acetic acid, and finally estimating as sulphate the sulphur in the remaining lead sulphide. This method was rather cumbrous and unsuitable to the determinations of amounts of sulphur of the order of 0·001 per cent.

An account of experiments on the corrosive nature of benzoles is given by Hoffert in the Second Report of the National Benzole Association[6] in 1925. Hoffert and his co-workers showed that the deposit formed in the case of benzoles is a mixture of cuprous and cupric sulphides, and is mainly cuprous sulphide in the case of benzoles which contain certain inhibitors of corrosion such as sulphonic acids, alkyl esters, and sulphur dioxide. They confirmed Ormandy and Craven's observation on the presence of elemental sulphur, and found also that mercaptans are corrosive to copper. With free sulphur dissolved in benzoles they found blackening occurred with copper in six hours at room temperature with concentrations down to 0·5 mg. per 100 ml. With brass, even as much as 0·01 gr. sulphur per 100 ml. in pure benzene caused in two months only slight tarnishing of the surface. Mechanical cleaning of the copper is recommended to avoid erratic results. Hoffert states that by refluxing the fuel with copper for a short time it is possible to determine definitely whether corrosion is likely to occur under ordinary conditions. He distinguishes also between the extent of the corrosive action and the amount of free sulphur, the corrosion being sometimes modified by the presence of inhibitors in the benzole. He criticises Ormandy and Craven's method, proposed in 1923, for the determination of free sulphur, and suggests decomposing with acid the sulphide obtained by shaking benzole with mercury. The hydrogen sulphide liberated is passed into ammoniacal cadmium acetate and the sulphide estimated iodimetrically. The causes of the presence of free sulphur in benzoles are discussed, and the suggestion is made that it may be due to the use of sulphuric acid in refining and the subsequent interaction of hydrogen sulphide and sulphur dioxide.

A systematic study of the corrosive effects of naphtha solutions of sulphur and sulphur compounds on metals was made by Wood, Sheely and Trusty[7]. They examined the copper dish method and also corrosion tests with metal strips at 50° C. and 100° C. for three hours and five days with and without the addition of water.

The strengths of solution used were considerably greater than are likely to occur in most spirits, e.g., 0·26 per cent. of free sulphur. The action of a number of sulphur compounds on a variety of the commoner metals was observed. The general conclusions were as follows. Mercaptans exhibit the widest range of activity while hydrogen sulphide comes next. Free sulphur is especially corrosive to copper, silver and mercury, but not so markedly so to any other metals investigated. Alkyl sulphides, disulphides, carbon disulphide and thiophene are not markedly corrosive. Silver and mercury are the most widely affected metals,

and tin the least. Heat increases corrosion effects, and in the case of some sulphur compounds and free sulphur, traces of moisture have considerable effect. Free sulphur, mercaptans and hydrogen sulphide seem to be the most active corrosive agents for copper. Brass is much less readily attacked.

Faragher, Morrell and Monroe[8] investigated the quantitative determination of sulphur and sulphur compounds in petroleum, and propose to estimate free sulphur by the difference in sulphur contents before and after shaking with mercury, using the standard A.S.T.M. method for sulphur determinations. The examples given are of mixtures containing 0·05 to 0·03 per cent. free sulphur. The accuracy of the total sulphur determination is not in general sufficient to permit the estimation of amounts of free sulphur such as occur in commercial fuels.

Kattwinkel[9] proposed to estimate the corrosive sulphur in benzoles by refluxing for one hour with half a gramme of copper-bronze and then either determining the difference in total sulphur content before and after treatment using Schenk's method, which involves combustion in a specially constructed lamp and titration of the products of combustion, or else liberating hydrogen sulphide by the action of acid on the copper sulphides and estimating this volumetrically.

A survey of the sulphur contents of 130 marketed American fuels was carried out in 1928 by Kraemer, Lane and Luce.[10] They found that of the 130 fuels only 12 had a sulphur content of 01 per cent. or more and only two showed corrosion on test, both of these being fuels of high sulphur content.

Rue[11] uses a "rapid corrosion test" comprising shaking 100 ml. of the gasoline with 1 ml. of mercury, decanting through a qualitative filter paper and examining visually the sulphide precipitate. He considers this to be more sensitive than the copper strip method.

Pierce[12] tests for carbon disulphide and free sulphur by means of Von Nagy Ilosva's reagent (a solution of copper sulphate in ammonium chloride and hydroxylamine hydrochloride solutions), estimating the amount colorimetrically, but this method does not appear suitable for routine examination of motor fuels.

A recent paper dealing with corrosive sulphur is that of Birch and Norris.[13] These investigators state that certain acid-refined petroleum distillates contain a substance which is corrosive to copper at the boiling point of the distillate, but which does not react with mercury in the cold. This substance is therefore not free sulphur. They conclude from additional evidence that the corrosive material is an organic polysulphide, formed by the action of elementary sulphur on certain mercaptans.

Faragher, Morrell and Comay[16] discuss the thermal decomposition of organic sulphur compounds. The formation of free sulphur and hydrogen sulphide in some of these reactions has a definite bearing on the formation of the corrosive compounds in petroleum products.

Bandte[17] describes corrosion tests with copper strips and notes the effect of moist alcohol on the results.

A number of corrosion tests have been adopted by various official bodies for use in examining gasolines for specification purposes. The A.S.T.M., 1927[22] adopted as a tentative method the copper strip test at 122° F. which is used together with a similar test at 212° F. and a copper dish test first developed during the war by the United States Bureau of Mines[23] for controlling the purchases of fuel by the U.S. Government. Distillation over a copper strip is used by the B.E.S.A.[21] in their specification for white spirit. The Institution of Petroleum Technologists[19,20] adopted a copper dish test in its 1924 book of Standard Methods. This was replaced in 1929 by a modification of Ormandy and Craven's method for determining free sulphur, no other corrosion method being included. The methods of testing coal and its bye-products of the U.S. Steel Corporation[18] includes a method for detecting the corrosive action of benzoles depending on refluxing with a copper strip.

From a review of the literature it is seen that views on the methods of testing for the forms of sulphur which may cause trouble in the fuel system are very divergent.

It seems generally accepted that elementary sulphur is the substance chiefly responsible, but other compounds, e.g., mercaptans[4,7], sulphoxides[12] and polysulphides[13] may also have an appreciable effect while the inhibitory action of some other compounds seems marked in the case of certain benzoles. A comparison of the appearance obtained with copper strips or dishes is evidence that the effects are not always due to the same class of compound and it is often very difficult to decide from these tests whether or not a given spirit should be passed or failed.

A reliable and convenient method of estimating the total corrosive effect which may be produced under the most drastic conditions, would seem to be the safest way to evaluate this property. It would also be useful in standardising the quicker but less consistent and reliable "corrosion tests."

The experiments described below were undertaken with the object of devising a method of estimation which could conveniently be carried out on a batch of routine samples and also of correlating these results with the corrosion tests in general use in the laboratory.

Experimental.

The first part of the work was directed to devising a suitable method for the estimation of corrosive sulphur. This method should be rapid, accurate and simple as possible, need little attention and be capable of dealing with batches of up to six routine samples at a time.

None of the methods proposed meet these requirements entirely. The only three which appear suitable are the I.P.T. modifications of Ormandy and Craven's method[4, 20], Hoffert's modification of the method[9] and Kattwinkel's method.[9]

The original mercury method is criticised by Hoffert on the ground that loss of hydrogen sulphide when the mercuric sulphide is dissolved in acid, caused low results with the higher concentrations of sulphur. The method he proposes involves the setting up of an apparatus for distilling off hydrogen sulphide and absorbing this and the passing of hydrogen through the apparatus, which details make the method inconvenient when numbers of samples must be examined. The mercury method adopted by the I.P.T. avoids loss of sulphur by dissolving in aqua regia, but all these methods suffer from the disadvantage of requiring long shaking with mercury. This is laborious if carried out by hand; shaking machines of the type necessary to give the required violent reciprocating motion are seldon satisfactory in continued use. Again, Birch and Norris (*loc. cit.*) find polysulphides present which are not corrosive to mercury in the cold. Metals present in the fuel systems are chiefly copper and its alloys, and the temperature of the fuel, as has been shown in connexion with vapour lock investigations, may often rise to 60° C. or 70° C. in the carburettor and fuel lines.[24]

The suggestion of Sanders[1] and Kattwinkel[9] to reflux with copper would therefore seem to be more sound. The use of copper-bronze is found to be more convenient than of copper turnings and the preparation far more active. It is, however, impossible to estimate the small but significant amounts of free sulphur which occur in fuels by any method which depends on determining the difference in total sulphur contents before and after treatment. The other suggestion, to decompose the copper sulphides with acid and collect and titrate the hydrogen sulphide, suffers from the disadvantage attaching to this portion of Hoffert's method.

It was decided to adopt the method of refluxing with copper-bronze. Several methods were then tried in order to estimate the sulphur removed. These results obtained in this way were compared with those obtained by the Standard I.P.T. method.[20] All the fuels examined were, except where otherwise noted, actually marketed gasolines, benzoles or toluoles.

Preliminary Experiments.

It was first attempted to dissolve the mixture of copper-bronze and sulphides, obtained by refluxing with copper-bronze, in nitric acid, or aqua regia, but these methods gave low results owing to the loss of hydrogen sulphide. Decomposition of the sulphides with hydrochloric acid, absorption of the gas evolved in ammoniacal cadmium chloride and titration with iodine and thiosulphate gave results which were fairly accurate if precautions were taken to avoid oxidation, e.g., by removing air from the apparatus with hydrogen. Copper sulphide seems rather easily oxidised, however.

The following method was then tried out. 100 ml. of gasoline were refluxed for an hour on the sand-bath with 0·5 gr. of copper-bronze powder. The gasoline was then removed by decantation and the copper washed with light spirit, decanted and dried. The sulphides were then extracted by boiling for 15 mins. with 20 ml. of 5 per cent. potassium cyanide solution. In the case of high sulphur fuels the solution was decanted through a filter and the extraction repeated. The filtered extract was then treated with an excess of bromine, boiled, made acid with hydrochloric acid, boiled for half an hour and the sulphate precipitated with barium chloride.

Good results were obtained by this method, e.g., on Spirit 1, 8·25 mg. per 100 ml. free sulphur were found, while the mercury method (two extractions with mercury were necessary) gave 8·5 mg., the difference being of the order of the experimental error. Great difficulty was experienced in filtering off the mercury sulphide owing to blocking of the filter paper. It was necessary to complete the filtration with another Gooch crucible. This trouble is experienced even with moderately high free sulphur contents, and causes much loss of time. This method was quite satisfactory as regards manipulation; but for routine use it was considered desirable to find some reagent other than potassium cyanide to dissolve the copper sulphides.

It was then noted that bromine would quickly and easily dissolve not only the copper sulphide but the copper-bronze as well, thus readily yielding a solution from which sulphate could be precipitated and involving no possibility of loss of hydrogen sulphide. The procedure finally adopted is given below.

Copper-Bronze Method. Final Form.

About 0·5 gr. of copper-bronze powder is placed in a 250 ml. round-bottomed flask, fitted with a reflux double-surface condenser with a lead-off tube for any light vapours from gasolines. Six of these can be arranged for heating on a large sand-tray. 100 ml. of the gasoline or benzole are placed in each flask and boiled with reflux for about 1 to 1½ hrs. Even very large amounts of free sulphur are completely removed in this time owing to the large

surface of copper-bronze exposed and to the fact that the material is in suspension in the boiling liquid. The flasks may, with advantage, be given a shake round occasionally.

When the contents of the flask have cooled down a little and the copper settled out, the spirit is decanted carefully through a quantitative filter paper. The copper-bronze is then washed with light spirit and this also decanted through the filter. Filter paper and flask are then placed in the steam oven for a few minutes to dry. 40 to 50 ml. of distilled water are then added to the flask and excess of bromine then added until all the bronze and sulphide have dissolved. A little (2 or 3 ml.) of concentrated hydrochloric acid is then added and the solution washed into a 400 ml. beaker and the excess bromine boiled off. The filter paper is usually almost free from copper or copper sulphides, but this should also be treated with bromine. This can be done either in a separate beaker or by introducing the paper into the flask before adding bromine.

The bromine-free solution is then filtered, boiled and precipitated with barium chloride.

The results obtainable with this method were compared with those yielded by the I.P.T. standard method (see Table I). That agreement can be obtained by the same or different operators by the copper-bronze method is shown by Table II.

Copper-bronze powder from two sources was used in these experiments. The first was a Kahlbaum product and the second was obtained from the B.D.H. Blank experiments were carried out to determine the amount of sulphur introduced by the reagents. Using Kahlbaum copper-bronze, the blank was found to be 0·04 mgrs., while with the B.D.H. material 0·13 mgrs. was obtained.

TABLE I.

Fuel.	Free sulphur mgrs./100 ml. I.P.T. method.	Copper-bronze method.
2. Gasoline	0.1 ..	0.1
3. Benzole	0.2 ..	0.2
4. Benzole blend	0.3 ..	0.3
5. Benzole	0.35 ..	0.45
6. Benzole blend	2.6 ..	2.65
7. Toluole	4.6 ..	4.75
8. Gasoline, cracked.. ..	7.4 ..	6.9

TABLE II.

Fuel.	Free sulphur mgrs./100 mls. Copper-bronze method. Observer A.	Observer B.
9.	0.02	0.06
10.	0.49	0.48 0.43
11.	1.52 1.72	1.52
12.	4.37	4.53

(These results are corrected for blanks. The first result on Spirit 12 was obtained with B.D.H., and the second with Kahlbaum copper-bronze.)

The method thus seems to be reproducible to about 0·1 mgrs./100 ml., which compares favourably with that obtained by Ormandy and Craven on spirits containing pure elementary sulphur.

Two distillates from a Persian crude, washed with 0·5 per cent. sulphuric acid and then soda, were examined for corrosive sulphur. The 90/120° C. fraction showed 186 mgrs./100 ml. and the 120/150° C. fraction 179 mgrs. by the copper-bronze method. The manipulation was quite easy throughout. With the mercury method, it was impossible to deal with the distillates except by diluting down with sulphur-free spirit to about one-fiftieth of the concentration.

"Corrosive" and Total Sulphur.

As expected, it was found from a comparison of the free and total sulphur contents of a number of fuels that there is no relation whatever between the amounts of the two types of sulphur, either in the case of gasolines or benzoles. This is illustrated by a few results given below:

TABLE III.

Fuel.	Free sulphur mgrs./100 ml.	Total sulphur per cent. weight.
13. Gasoline	1.8 ..	0.05
14. Gasoline	3.0 ..	0.36
8. Gasoline	6.9 ..	0.09
15. Benzole	0.1 ..	0.4
16. Benzole	0.4 ..	0.3
17. Benzole	1.3 ..	0.08
18. Benzole	1.6 ..	0.16
19. Benzole	4.2 ..	0.57

Corrosion Tests and Free Sulphur Content.

The next problem is to determine what relation, if any, exists between the content of "free sulphur" determined in this way and the type of "corrosion test" which is generally employed, with the object of selecting the most satisfactory of these and interpreting the results as accurately as possible.

Accordingly, the free sulphur contents and the results of corrosion tests were determined, and the results are given in Table IV, a description of the copper surface, the usual description reported, and the approximate order of the corrosive effects being included. The tests used for this purpose were the Copper Dish, and the U.S.B.M. copper strip tests at 122° F. and 212° F.[23], these being the most widely known and used.

TABLE IV.

Fuel.	Free sulphur mg./100ml.	U.S.B.M. Test at 122° F. Order of Merit.	Usual Description.	Remarks.	U.S.B.M. Test at 212° F. Order of Merit.	Usual Description.	Remarks.	Copper Dish Test. Order of Merit.	Usual Description.	Remarks.
20. Gasoline ..	0.04	A	Good.	Practically no discolouration.	A	Good.	Very slight discolouration.	B	O.K. Passes.	Slight red and blue tints, no deposit.
21. Benzole ..	0.2	B	Good.	Very slight brownish discolouration.	C	Fairly good.	Slight brown discolouration.	C	O.K. Passes.	Red and blue tints.
22. Benzole Blend	0.3	C	Good.	Very slight brownish discolouration.	D	Fair.	Greenish - brown discolouration.	A	Passes.	Little sign of corrosion. Slight gum.
23. Spirit ..	0.3	D	Good.	Very slight brownish discolouration.	—	—	—	D	Passes.	Slight red and blue tints.
24. Benzole ..	0.45	E	Fairly good.	Slight brown discolouration.	B	Fair.	Slight brown discolouration.	F	Barely passes.	Green-grey tint. Slight black deposit.
25. Benzole ..	0.5	H	Fair.	Slightly more discolouration — brown.	—	—	—	E	Barely passes.	Very slight black deposit.
26. Gasoline ..	0.75	F	Fairly good.	Patches of brown, otherwise quite free.	—	—	—	—	—	Very gummy. No signs of corrosion.
27. Gasoline ..	0.85	G	Fairly good.	Patches of brown, otherwise quite free.	—	—	—	—	—	Very gummy. No signs of corrosion.
28. Gasoline ..	1.32	M	Poor.	Brown tint.	—	—	—	—	—	—
11. Gasoline ..	1.55	L	Poor.	Brown tint.	—	—	—	—	—	Very gummy. No signs of corrosion.
29. Gasoline ..	1.85	J	Poor.	Brown and red tints.	—	—	—	—	—	—
30. Gasoline ..	2.1	N	Poor.	Brown tints.	—	—	—	—	—	—
6. Benzole-Toluole Bl.	2.5	R	Very bad.	Uniform blue-grey tint.	E	Bad.	Black thin film over surface.	G	Fails.	Black deposit.
31. Gasoline ..	3.0	O	Bad.	Red and brown tints.	—	—	—	I	Fails.	Black deposit.
32. Gasoline ..	3.65	K	Poor.	Reddish tint.	—	—	—	—	—	—
33. Gasoline ..	4.0	P	Bad.	Red and blue tints.	—	—	—	J	Fails.	Heavy black deposit.
7. Toluole ..	4.5	S	Very bad.	Black coloured in patches. Slight scaling.	F	Very bad.	Heavy black deposit with tendency to scale.	K	Fails	Hard coherent black film.
34. Benzole ..	4.5	I	Fairly good.	Slight brown tints.	—	—	—	H	Fails.	Black deposit.
35. Benzole ..	5.7	Q	Bad.	Red, blue and green tints.	—	—	—	—	—	—
8. Gasoline ..	6.9	T	Very bad.	Black film over whole surface.	G	Very bad.	Very heavy black deposit. Scaling.	L	Fails.	Very heavy black deposit. Scaling badly.

(The corrosion increases from A to T.)

From the results obtained in Table IV certain general conclusions may be drawn. The U.S. Bureau of Mines test gives fairly good agreement with the free sulphur content in the case of gasolines. Exceptions sometimes arise, however, a gasoline giving no corrosion in the 122° F. test showing very heavy corrosion at 212° F. These exceptions are more frequent with benzoles and toluoles and blends containing these substances. Sample No. 34, a benzole, gives a fairly good corrosion test at 122° F., in spite of containing 4·5 mgms. of free sulphur per 100 ml. It fails badly on the copper dish test however, showing a black deposit. On the other hand, No. 6, which is a benzole-toluole-gasoline blend, and No. 7, a straight toluole, are both worse on the 122° F. test than would be expected from their free-sulphur contents. Discrepancies of this kind are probably attributable to the presence of inhibitors or other substances which modify the course of the corrosion (*cf.* [5]). The effect of the inhibitor seems to decrease on blending a benzole behaving in this way with gasoline. Cases have been noted where a fuel originally non-corrosive, judged by this test, fails to pass after storage. Gasoline No. 8 is such a case.

The U.S. Bureau of Mines test at 212° F. gives results which correspond fairly well with the free sulphur content. The objection to this method is that the volatile portions of gasolines and a large part of benzoles may distill off during the three hours heating, thus leaving part of the strip uncovered and the lower portion immersed in a liquid which may contain a much higher proportion of corrosive material than the original fuel.

Very similar objections apply to the copper dish test, as fuels evaporate at very different rates, apart from differences caused by rate of heating and air currents. Moreover, the results may be modified by the presence of gum-forming compounds. In the cases of gasolines, 26, 27 and 11, the copper was completely protected from corrosion, although appreciable amounts of corrosive sulphur are present. This protection will occur in lesser degree with gasolines giving smaller amounts of gum.

In connexion with the temperature at which corrosion tests should be carried out, a recent survey of fuel-line temperatures in connexion with vapour-lock tendencies (Bridgeman and White[24] is of interest. They show that the average maximum temperature attained in the fuel-system after idling or hill-climbing is 60° F. above atmospheric, while in extreme cases the rise may be as much as 90° F. This means that in warm weather temperatures of about 140° F. (60° C.) are attained and temperatures of 160° F. (71° C.) may be reached in bad cases. This is important, considering that some fuels show no corrosion at 122° F., but severe corrosion at 212° F. In this case, the reaction between copper and certain

sulphur compounds, possibly polysulphides, evidently becomes appreciable at some temperature between 122° F. and 212° F.

Dealing with corrosion from the user's point of view, McVitty[21] says, in a recent paper on aircraft fuels:

"Lately the merits of some kind of copper strip test at low temperature, as compared with the copper dish test for corrosion, have been discussed at some length. We have been unable to find conclusive proof, however, that corrosion troubles are never experienced with fuels passing some kind of copper strip test. Unless some form of copper strip test is demonstrated to be clearly superior to the copper dish corrosion test from the point of view of the operator, for the operator to include an additional test in his routine test procedure would be foolish, as the copper dish corrosion test has already been made after the copper dish gum content has been found. Serious corrosion has been experienced with fuels that failed to pass the copper dish test for corrosion, and we have no evidence that the corrosive action increased with the age of the fuel."

And again:

"Securing benzole that would pass the copper-dish corrosion test in a 15 per cent. benzole-gasoline blend has always been difficult, even though the benzole would not discolour a copper strip immersed in it for three hours at 122° F., and although the sulphur content of the benzole was less than 0·09 per cent."

Benzoles and toluoles seem to contain, in general, the largest amounts of corrosive sulphur, but occasionally gasolines are found with very marked corrosive properties—e.g., No. 8. It is evident from the appearance of the corroded copper surfaces that corrosion can be due to a variety of sulphur compounds.

Taking all the above considerations into account, it would appear that the determination of the total amount of corrosive material by a method such as is described here gives the most reliable means of estimating possibilities of corrosion in the fuel systems of automobiles. "Corrosion tests" depending on heating with copper strips for definite times at certain temperatures are all open to objection and give unreliable results. It is far safer to estimate the maximum amount of corrosion which may occur. Fuels containing up to 0·5 mgrs. free sulphur in 100 ml. may be regarded as non-corrosive; those containing up to 1 mgr. as reasonably good, while fuels containing much more than 1 mgr. are liable to give rise to trouble which, in some circumstances, may be serious.

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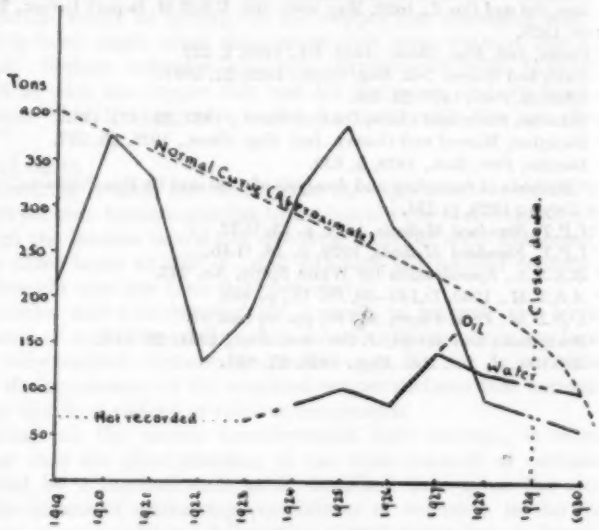
CURRENT PETROLEUM NOTES.

Turner Valley, Alberta.—The most recent well of the Merland Oil Co., in the extreme south of the Turner Valley oilfield, is reported to be yielding about 25 million cubic feet of wet gas daily in spite of heavy gas pressure to prevent freezing. It is expected that the yield of naphtha will be as high as 500 barrels daily. The new strike was made at about 5550 feet and is believed to prove the existence of a large producing area.

The Oil Well at Hardstoft.—In 1928 the oil well at Hardstoft was dealt with in a paper read before the Institution of Petroleum Technologists and the developments which had taken place up to that date were described. It may be both interesting and important to place on record what has happened since.



PRODUCTION CURVE HARDSTOFT NO. 1.

The No. 1 well is still producing oil, but the proportion of water to oil is gradually increasing.

In 1928 78 tons of oil and 118 tons of water were produced.

1929 The well was shut down, but would still flow slowly of its own accord when opened up; 6¼ tons of oil were obtained in this manner.

1930 The well was cleaned out and pumped occasionally and produced 60 tons of oil and 97 tons of water.

Appended is the curve of production up to the end of the year 1930. It is the curve shown in the 1928 paper brought up to date. It will be seen that the curve suggested for normal production appears to be as accurate as it

was possible to draw it. It will also be noted that the quantity of water produced in relation to oil did not go on increasing as was suggested. Comparatively, the yield of water-gas increased in regard to oil, but the actual yield of water has diminished.

Now the well has not been regularly pumped. The working has been both occasional and spasmodic, while for one whole year—1929—nothing whatever was done except to open up the well and let it flow on one or two occasions. It is surprising in the circumstances that the amount of oil produced has been as large as the figures show.

The curves seem to suggest two things: first, the rather obvious point that the well would have produced a considerably larger quantity of oil if it had been regularly pumped or flowed and that the normal curve in the earlier diagram would, in that case, show too steep a decline, and secondly, that the water is not flooding out the oil and could be kept down and perhaps reduced to a minimum by regular but not excessive pumping.

The No. 2 well is still producing gas, but no use is being made of it.

I am again indebted to Captain Penrose for the data upon which this note is based.

ARTHUR WADE.

BOOKS RECEIVED.

THE ACTION OF HYDROGEN ON COAL. By I. A. Crawford, F. A. Williams, J. G. King and F. S. Sinnatt. Fuel Research Technical Paper No. 29. London: H.M. Stationery Office. 1931. Pp. vi.+37; 15 figures.

The work on hydrogenation at the Fuel Research Station has been directed more particularly to the nature of the reactions and their applicability to British coals. It was early noticed that a less drastic treatment than that required for liquefaction had a marked effect on caking properties and that a weakly caking coal could be converted to a strongly caking one, and that some caking properties could even be conferred on anthracite. The present paper, which is the first of a series, deals with this aspect of the investigation, which is termed "partial hydrogenation."

REPORT OF TEST. By Director of Fuel Research on a Retort of the Bussey Coal Distillation Company, Ltd., at Glenboig, Lancashire. London, H.M. Stationery Office, 1931. Pp. vi.+28. 9d. net.

During a 124-hour test 89.14 tons of a weakly caking coal were carbonised. The retort, which is heated internally by burning part of the coke with a steam-air blast admitted near the base, was operated satisfactorily. The yield per ton of coal (11.1 per cent. moisture as charged) was 10.2 cwt. coke, 17.61 gal. tar, 49.4 gal. liquor, 40,270 cu. ft. gas (76.0 therms), and 3.24 gal. gas spirit. Of the coke, 17 per cent. was breeze passing through a ¼-in. screen. The lump coke forms a satisfactory fuel for domestic grates of the vertical bar type.

ERRATA.

"Catalytic Addition of Gaseous Hydrochloric Acid to Unsaturated Hydrocarbons," pp. 225–241. In Table I. the second hydrocarbon should be 2-Methylbutane (Isopentane). This also applies to other references to the same hydrocarbon in the text.

"Intrusive Salt Domes in Coastal Asia, South-Western Arabia." Page 325: the last sentence of footnote 8 should be deleted, as the author has now traced Guma. Page 330, line 9: for "conical" read "ancient."

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